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DIANA LAURA SIRGHI

PERSONAL DATA

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EDUCATION

- 1988 – 1992 High School, (Mathematics and Physics), Calarasi, Romania
- 1992 – 1997 Faculty of Physics, University of Bucharest (general physics)

  B.Sc.Degree.

  Diploma thesis title:

  Study of electroproduction reaction: $e + p \rightarrow e + K + \Lambda(1520)$

  Supervisor: Prof. Dr. Tatiana Angelescu (University of Bucharest)

  Grade: 10 (rating 10 for excellent)
- 1997-1998 Specialisation in Particle Physics, Faculty of Physics, University of Bucharest

  M.Sc.Degree.

  Diploma thesis title:

  Production of strange resonances

  Supervisor: Prof. Dr. Tatiana Angelescu (University of Bucharest)

  Grade: 10
- 2004 - 2013 *Ph.D. programme* in Faculty of Physics, University of Bucharest, Particle Physics Department

  Ph.D in physics

  Diploma thesis title:

  The physics of kaonic atoms - The first measurement of kaonic - ^{3}He atom

  Supervisor: Prof. Dr. Tatiana Angelescu (University of Bucharest)

  Carlo Guaraldo (INFN-LNF)

  Catalina Curceanu (INFN-LNF)

  Grade: *Summa cum Laude*

PROFESSIONAL EXPERIENCE

- 1997 – 1999 *Teaching Assistant* at Faculty of Physics, University of Bucharest FORTRAN language
- 1998 – 2000 *Teaching Assistant* at Faculty of Physics, University of Bucharest Kinematics of elementary particles
- 1998 – 2005 *Junior Assistant Researcher* at HEP Dept., IFIN-HH, Bucharest, after concourse
- 1998 – 2002 *Researcher* at LNF-INFN with special funds for foreigner guest (F.A.I.)
- 2005 – *Permanent position as Assistant Researcher* at HEP Dept., IFIN-HH, Bucharest, Romania, after concourse
- 2002 – 2004 *INFN – Postdoctoral fellowship for non-italian citizens*, with research activity at LNF – INFN, after concourse.
- 13 September 2004- 12 September 2006 Contract INFN (Art. 2222) at LNF-INFN
- 13 September 2006- 31 December 2008 Contract INFN (Art. 2222) at LNF-INFN
- 07 January 2009- 05 September 2009 Contract INFN (Art. 2222) at LNF-INFN
- 07 September 2009- 01 September 2014- Contract INFN (Art. 23) at LNF-INFN

- 02 September 2014-
  01 January 2015- Contract INFN (Art. 2222) at LNF-INFN

- 02 September 2015-
  01 February 2016- Contract INFN (Art. 2222) at LNF-INFN

- 02 February 2016 -
  30 April 2016 Honorarium Contract at Ruhr Universität Bochum (RUB) (Bochum, Germany), with scientific activity at LNF-INFN

- 01 May 2016 -
- 31 December 2016 Honorarium Contract at Ruhr Universität Bochum (RUB) (Bochum, Germany), with scientific activity at LNF-INFN

- 09 January 2017-
  28 February 2017 Contract INFN (Fondi FAI) at LNF-INFN

- 01 March 2017 -
- 30 June 2017 Honorarium Contract at Stefan Meyer Institute for Subatomic physics (Vienna, Austria), with scientific activity at LNF-INFN

- 03 July 2017-
  02 July 2020- Contract INFN (Assegno di Ricerca) at LNF-INFN

SCIENTIFIC ACTIVITY

SIRGHI DIANA LAURA

During 1997 I started to work at Faculty of Physics, University of Bucharest in the Elementary Particles Department. My first activity concerned the study of kinematic conditions necessary to produce the baryonic resonance Λ(1520) in electroproduction reactions.

Since 1998 I participated in various international collaborations in the sectors of particle and nuclear physics. My scientific line of activity was dedicated to:

I. Research in the field of hadronic and nuclear physic: studies of kaonic atoms and of the antikaon-nucleon/nuclei interactions: DEAR experiment, SIDDHARTA experiment, SIDDHARTA-2 experiment, AMADEUS initiative.
II. Quantum foundational research: study of the possible violation of the Pauli exclusion principle: VIP and VIP2 experiments.

Research in the field of hadronic and nuclear physics: studies of kaonic atoms and of the antikaon-nucleon/nuclei interactions

The DEAR experiment

The determination for the first time at a percent level accuracy of the $\bar{K}N$ scattering lengths through the measurement of the shift and the broadening due to strong interaction of the K_α line of kaonic hydrogen and kaonic deuterium was the task of the DEAR (DAΦNE Exotic Atom Research) experiment. The aim is to investigate K-nucleon physics at low energy and to determine the so-called kaon-nucleon sigma terms which give the degree of chiral symmetry breaking and are connected to the strangeness content of the proton.

The goal of the DEAR experiment was to measures the 2p $\rightarrow$ 1s (K_α) transitions in kaonic hydrogen and kaonic deuterium and compares the energy of the line with the position calculated on the basis of a pure electromagnetic interaction only, obtained solving a Klein-Gordon equation. The shift ε and the width Γ of the line, due to the strong interaction, are related to the real and imaginary part of the scattering length a_{K^-p} by a classical relation (Deser relation): $\varepsilon + i\Gamma/2 = (412 \text{ eV fm}^{-1}) a_{K^-p}$. A similar relation is valid for kaonic deuterium. The observable scattering lengths a_{K^-p} and a_{K^-d} are then related to the isospin dependent scattering lengths a_0 and a_1 (I=0,1).

The experiment takes advantage of the unique features of the "kaon beam" from φ-decay in DAΦNE: low momentum, monochromatic, high purity and good intensity. The experimental setup consists of a cryogenic and pressurized hydrogen target, in order to optimize the yield of the 2p→1s transition, avoiding the suppression due to the Stark effect and, as detector, of an array of Charge-Coupled Devices (CCD). The CCDs are the best detectors for soft X-ray detection (< 20 KeV), in terms of resolution and, above all, background rejection capability due to their pixel structure.

The measurements requires, in the case of hydrogen, the identification of a signal of definite energy ($\approx$ 6.5 keV) over a huge background and the measurement of the identification in position and width position of K_α line with a precision at the level of percent, in order to measure its shift and broadening, with respect to the electromagnetic position due to $\bar{K}N$ strong interaction.

Before the measurement of kaonic hydrogen, kaonic nitrogen was measured. This measurement was done for the many reasons: to demonstrate the feasibility of the DEAR technique – i.e. the use of the kaons delivered by DAΦNE to create exotic atoms witch then are detected by the CCDs. The transition yield in kaonic nitrogen is at least 30 times higher than the one of kaonic hydrogen – so that a faster feedback is possible and, accordingly, an accurate study of the target condition and degrader optimization is possible. Moreover, the measurement of kaonic nitrogen has an important scientific meaning, since it gives important information concerning the evolution of cascade processes in exotic atoms by determining the yields of the kaonic nitrogen transitions which are in the range accessible to DEAR apparatus.

The kaonic nitrogen spectrum has been measured in two periods (May 2001 and April 2002), with two different setups.

As a result of the first measurement, the 7→6 at 4.6 KeV and 6→ at 7.6 keV transitions were measured at 5 σ in a spectrum characterized by the presence of electronic lines due to electronic excitations of the materials of the setup.

The second, definitive measurement of the kaonic nitrogen was performed with the same setup to be used for the kaonic hydrogen measurement. This setup is characterized by a target built on pure kapton, with fiberglass reinforcement. Only two electronic excitations (Si and Ca) could be eventually seen. The detectors are large area CCDs of last generation. All the electronics, designed at LNF, gave very good results in terms of resolution (140 eV at 6 keV) and stability of the system

After the background subtraction the statistical significance of the signal was 12σ.

The yields of 3 lines of Kaonic nitrogen were measured for the first time. The results are: (41.5 ± 8.7 ± 4.1)% for the transition n = 7 → 6; (55.0 ± 3.9 ± 5.5)% for the transition n = 6 → 5; (57.4 ± 15.2 ± 5.7)% for the transition n = 5 → 4. These results are stimulated the activity in the field of atomic cascade for exotic atoms.

The main goal of the DEAR experiment was the measurement of the kaonic hydrogen.

In order to perform the kaonic hydrogen measurement, the target was filled with hydrogen in cryogenic and pressurized conditions: 23 K and 1.82 bars.

The kaonic hydrogen measurement lasted from 30 October to 23 December 2002.

The values for shift and width of the K_α line of kaonic hydrogen are: ε_{1s} = -192 ± 37 (stat.) ± 6 (syst.) eV; Γ = 246 ± 111 (stat.) ± 30 (syst.) eV.

These results represent the best measurement performed on kaonic hydrogen up to that moment. It is as well a strong motivation for the community working on the low-energy kaon-nucleon interactions.

My research activity in the DEAR experiment:

- ***<u>Monte Carlo simulation</u>***
  - ***In the DEAR experiment I was involved in the group dedicated to the Monte Carlo simulations to optimize the number of stopped kaons and the x rays detected by the CCDs. Because of the finite, although small, crossing angle (28mrad) between electron and positron beams, the ϕ particles were slightly boosted toward the outside of the DAΦNE rings. Therefore, the momenta of the two kaons in the K^+K^- pairs had a small angular dependence. The boost effect was compensated by degraders composed of step like multilayer Hostaphan foils. The structure and the thickness of the degrader were decided using the Monte Carlo simulations.***
  - ***Monte Carlo simulation to evaluate the kaon stopping efficiency in the target gas, the x-ray absorption in gas and in the target windows, and the CCD quantum efficiency in order to estimate the transition yields of the kaonic nitrogen measurement,***
  - ***Monte Carlo simulations for studying the effects of varying the yield ratios, as well as the fit energy range to be included in the systematic error for the determination of the shift and width for the kaonic hydrogen atom.***
- ***<u>Measurement and data analysis of the kaonic nitrogen data</u>***
  - ***I was involved in the crucial phase of background reduction using a simplified setup, with a nitrogen target at NTP, equipped with 4 CCD-05. A reduction of background hitting the CCDs of about one order of magnitude could be finally obtained.***
  - ***I have played a relevant role in the measurement and data analysis of the kaonic nitrogen data in the framework of the DEAR collaboration finalized with the extraction of the yields of 3 lines of Kaonic nitrogen, which were measured for the first time.***
- ***<u>Measurement and data analysis of the kaonic hydrogen data</u>***
  - ***I participated to all the steps for the measurement and data analysis of the kaonic hydrogen data finalized with the extraction of the values for shift***

and width of the K_α line of kaonic hydrogen, which represent the best measurement performed on kaonic hydrogen up to that moment.

The SIDDHARTA experiment

Starting from the success of DEAR measurement, a continuation of the scientific program on exotic atoms was performed in SIDDHARTA (SIlicon Drift Detector for Hadronic Atoms Research by Timing Application), with the aim to reach a precision of few eV of kaonic hydrogen and the first-ever measurement of the kaonic deuterium X-rays to determine the strong-interaction energy-level shifts and widths of the lowest lying atomic states.

The precision of the DEAR experiment was limited by a signal/background ratio of about 1/70. To significantly improve this ratio, a breakthrough is necessary. An accurate study of the background sources present at DAΦNE was redone. The background includes two main sources: synchronous background: coming together with the kaons - related to K^- interactions in the setup materials and also to the Φ-decay processes; it can be defined as hadronic background; asynchronous background: final products of electromagnetic showers in the machine pipe and in the setup materials originating from particles lost from primary circulating beams either due to the interaction of particles in the same bunch (Touschek effect) or due to the interaction with the residual gas.

Accurate studies performed by DEAR showed that the main background source in DAΦNE is of the asynchronous type, which shows the way to reduce it. A fast trigger correlated to a kaon entering into the target would cut the main part of the asynchronous background.

X rays were detected in DEAR by using CCDs (Charge-Coupled Devices), which are excellent X-ray detectors, with very good energy resolution (about 140 eV FWHM at 6 keV), but having the drawback of being non-triggerable devices (since the read- out time per device is the order of 10 s).

A recently developed device, which preserve all good features of the CCD (energy resolution, stability, linearity), but additionally is triggerable – *i.e.* fast at the level of 1 μs), was implemented. This new detector is a large –area Silicon Drift Detector (SDD) (1 cm^2) specially designed for spectroscopic application.

The trigger in SIDDHARTA is given by a system of scintillators which recognize a kaon entering the target by making use of the back-to-back production mechanism the charged kaons at DAΦNE from Φ decay.

By triggering the SDDs, the asynchronous e.m. background (mainly due to the Touschek effect) can therefore be eliminated.

The SIDDHARTA final setup was built, assembled and tested in the period 2003-2007. This setup contains about 144 SDDs (each one of 1cm^2), which are positioned around a target made of kapton, 75μm thick, reinforced with an aluminium grid, filled with cryogenic gas.

SIDDHARTA was installed on DAΦNE in autumn 2008 and took data till late 2009.

In addition to the measurements of kaonic hydrogen and kaonic deuterium, we have performed the measurements of kaonic helium transitions to the *2p* level (L-lines): for the first time in a gaseous target for kaonic helium4 and for the first time ever for kaonic helium3.

To test and optimize our experimental technique, we measured the L-transitions for kaonic helium4 atoms, in particular the transition *3d→2p* transition. The use of this transition is motivated by its yield, a factor at least 10 times higher than the kaonic hydrogen K_α one.

The measurements of kaonic ^4He X-rays performed in the 70's and 80's introduced a serious problem; *i.e.*, inconsistency between theory and experiment both in the shift and width of the kaonic ^4He 2*p* state.

Part of the data for kaonic ^4He atoms, was taken for about two weeks in January 2009, while a ^{55}Fe source was installed inside the apparatus in order to monitor the stability of the SDD X-ray detection system.

The result obtained from these data for the *2p* level strong interaction shift of the kaonic ^4He was 0±6(stat)±2(sys) eV. The kaonic helium has physics interest in itself.

Prior to the experiment by the KEK E570 group, the average result of the three previous experiments -43± 8eV, while most of the theoretical calculations give a shift of

0 eV. This five sigma discrepancy between the theory and experiments was known as the ``kaonic helium puzzle".

A resolution of this long standing puzzle provided by the E570 group was firmly established by the SIIDHARTA published results.

During the SIDDHARTA data taking, we measured also the L-transitions for kaonic ^{3}He, for which no experimental data existed until now.

The first measurement of the kaonic ^{3}He X-rays, which is extremely important in view of a possible shift of the kaonic ^{3}He 2*p* level, as well as a possible isotope difference of the 2*p* level shifts between kaonic ^{3}He and ^{4}He depending on the strength of the K^-–^{3}He and K^-–^{4}He interaction, was done by the SIDDHARTA experiment in the last three days of data taking, nearly November 2009. The total integrated luminosity for this measurement was about 10 pb^{-1}.

The SIDDHARTA experiment measured, for the first time, the energy of the kaonic ^{3}He $3d \rightarrow 2p$ transition using a gaseous ^{3}He target. The strong-interaction shift of the kaonic ^{3}He 2*p* state was determined to be -2±2(stat)±4(syst.) eV.

Using the same setup as well as the same measuring and analysis procedures, kaonic ^{4}He $3d \rightarrow 2p$ X-rays were re-measured over short periods for a very first look at a possible isotope shift between kaonic ^{3}He and ^{4}He.

The strong-interaction shift of the kaonic ^{4}He 2*p* state was determined to be +5±3 (stat)± 4 (syst) eV. This result is in agreement, within the errors, with the results reported by the E570 and SIDDHARTA collaborations.

Since the present results both of the kaonic ^{3}He and ^{4}He shifts were determined with the same procedures, their difference gives directly a first indication that the kaonic ^{3}He–^{4}He isotope shift is rather small, which is expected also in theories.

The SIDDHARTA experiments measured also the strong-interaction widths both of the kaonic ^{3}He and ^{4}He 2*p* states, where kaonic ^{3}He was measured for the first time.

The determined width of kaonic ^{3}He 2*p* state is 6±6 (stat.)± 7 (syst.) eV, and the width of kaonic ^{4}He 2*p* state is 14± 8 (stat.)± 5 (syst.) eV.

The width of kaonic ^{4}He was found to be much smaller than the value of 55 ± 34 eV determined in the experiments performed in the 70's and 80's. The strong-interaction 2*p* level widths both of kaonic ^{3}He and ^{4}He are in good agreement with the theoretical estimated values of 1–2 eV. No abnormally large widths were found either in kaonic ^{3}He or ^{4}He.

The X-ray measurements of the kaonic helium isotopes (^{3}He and ^{4}He) play an important role for understanding low-energy QCD in the strangeness sector.

The *KN* system at threshold is a sensitive testing ground for low energy QCD, especially for the explicit chiral symmetry breaking. Therefore, the SIDDHARTA experiment measured the *K*-series X-rays of kaonic hydrogen atoms. The measurement of the kaonic hydrogen atoms was performed in the period 15 March-31 July 2009 and during October 2009, for a total of about 400 pb^{-1} of integrated luminosity.

The SIDDHARTA experiment performed the most precise measurement of the *K*-series X-rays of kaonic hydrogen atoms. This was made possible by the use of new triggerable X-ray detectors, SDDs, developed in the framework of the SIDDHARTA project, which lead to a much improved energy and time resolution over the past experiments and much lower background in comparison with the DEAR experiment.

The *1s*-state strong-interaction shift ε and width Γ of kaonic hydrogen were determined to be:

$\varepsilon = -283 \pm 36(stat) \pm 6(syst)\ eV,\ \Gamma = 541 \pm 89(stat) \pm 22(syst)\ eV$

The results obtained for shift and width does provide new constraints on theories, having reached a quality which will demand refined calculations of the low-energy *KN* interaction.

The SIDDHARTA experiment performed also an exploratory kaonic deuterium measurement, the kaonic deuterium data were collected in October 2009, for a total integrated luminosity of about 100 pb^{-1}. The poor statistics of the data does not allow to fit the shift and width for the kaonic deuterium, the presence of the signal itself having a significance of 2σ. From the measurement of kaonic deuterium, the K_α and K_{tot} yields of the K-series transitions of $Y(K_\alpha) = 0.0019 \pm 0.0012$ and $Y(K_{tot}) = 0.0077 \pm 0.0051$ were derived.

My research activity in the SIDDHARTA experiment:

- ***<u>Monte Carlo simulation</u>***
  - ***I performed the Monte Carlo simulations for the SIDDHARTA apparatus, to optimize the critical parameters of the setup, like target size, gas density, detector configuration, degrader size and shielding geometry. The structure and the thickness of the degrader were decided using the Monte Carlo simulations.***
  - ***Monte Carlo simulation to estimate the absolute yields of the K-series of the kaonic hydrogen atoms. The values obtained for the K-series absolute yields confirmed the density dependence of the yields predicted by cascade calculations.***
  - ***Monte Carlo simulation for kaonic deuterium in order to obtain the experimental efficiencies for the evaluation of the limits on the yields of the kaonic deuterium transitions.***
- ***<u>Measurement and data analysis of the kaonic helium 3 and kaonic helium 4 data</u>***
  - ***I was initially involved in the test of SDD prototypes which were performed in 2003 and 2004 at the Beam Test Facility of Frascati (BTF), in realistic (i.e. DEAR-like) conditions. During these tests, a trigger rejection factor of 5×10^{-5} was measured.***
  - ***I have performed on-line analysis during the whole data taking period for SIDDHARTA experiment; I was monitoring the detector calibration: the low and the high voltage values for the SSDs, as well as the energy scale of the detectors' response; I have played a relevant role in the measurement and data analysis of the kaonic helium 3 and kaonic helium 4, finalized with the extraction of the values for shift, width and yield of the K_α line of kaonic helium 3 (measured for the first time) and kaonic helium 4 (measured for the first time in a gaseous target). The first measurement of the kaonic helium 3 atoms was the subject of my PhD thesis.***

- ***Measurement and data analysis of the kaonic hydrogen data***
  - ***I participated to all the steps for the measurement and data analysis of the kaonic hydrogen data finalized with the extraction of the values for shift and width of the K_α line of kaonic hydrogen, which represent the most precise measurement of the K-series X-rays of kaonic hydrogen atoms.***
- ***Measurement and data analysis of the kaonic deuterium data***
  - ***I participated to all the steps for the measurement and data analysis of the kaonic deuterium data finalized with the extraction of the upper limits for the yields which turned out to be (C.L. 90%) $Y(K_{tot}) < 0.0143$ an $Y(K_\alpha) < 0.0039$.***

The SIDDHARTA-2 experiment

The kaonic deuterium x-ray measurement represents the most important experimental information missing in the low-energy antikaon-nucleon interactions field.

For further study of the *KN* interaction, it is essential to measure the kaonic-deuterium *K*-series X-rays to disentangle the isoscalar and isovector scattering lengths.

The kaonic hydrogen result obtained by the SIDDHARTA experiment combined with deuterium data to be collected in the SIDDHARTA-2 experiment will provide invaluable knowledge about the behavior of low-energy QCD in the strangeness sector.

The experimental challenge of the kaonic deuterium measurement is the very small kaonic deuterium x-ray yield (1 order of magnitude less than for hydrogen) the even larger width, and the difficulty to perform x-ray spectroscopy in the high radiation environments of the machines delivering kaons.

The scientific aim of the SIDDHARTA-2 experiment is to perform a precise measurement of kaonic deuterium to determine X-ray transitions to the ground state (1s-level), such as to determine its shift and width induced by the presence of the strong interaction.

SIDDHARTA-2 is a new experiment, which was installed on DAΦNE in the spring of 2019, taking advantage of the experience gained in the previous SIDDHARTA experiment. The goal of the new apparatus is to drastically increase the signal-to background ratio, by gaining in solid angle, by taking advantage of the new SDDs with improved timing resolution, and by implementing additional veto systems, to improve by at least 1 order of magnitude the signal-to-background ratio, as compared to the kaonic-hydrogen measurement performed by SIDDHARTA.

The Monte Carlo simulation, to which I participated, considered the improvements done to the SIDDHARTA-2 apparatus, with the assumption that the values of shift and width of the 1s ground state of kaonic deuterium were −800 and 750 eV, respectively, as representative theoretical expected values. Using also the theoretical estimates for K_α d yields - one order of magnitude below the measured K_α p yields – the kaonic deuterium signal and background were simulated, in machine conditions similar to those which were present during the SIDDHARTA data taking in 2009.

With the planned setup improvements and with an integrated luminosity of about 800 pb^{-1}, SIDDHARTA-2 will be able to perform the first X-ray measurement of the strong interaction parameters - the energy displacement and the width of the kaonic deuterium ground state – data which are eagerly awaited by theoreticians. The shift will be determined with a precision of about 30 eV (expected shift 800 – 1000 eV) and the width with 70 eV (expected width 1000 eV), corresponding to a statistical significance of 20 σ for the K_α line. These values are of the same order as the SIDDHARTA results for kaonic hydrogen.

In 2019 the first setup, SIDDHARTINO, containing a reduce number of SDDs (8 SDDs units out of 48 units, each unit having 8 SDDs), aiming to measure kaonic helium to quantify the background in the new DAΦNE configuration, previous to the kaonic deuterium measurement, was installed and tested on DAΦNE. The luminometer detector and SDD calibration system were optimized, while DAΦNE was in commissioning. In early 2020 first collisions were achieved in DAΦNE and SIDDHARTINO was in optimization run. The kaonic helium-4 measurement with SIDDHARTINO will be done by the end of 2020 with the goal to have the at least the same level of background like for same measurement done with SIDDHARTA, followed by the kaonic deuterium measurement with the SIDDHARTA-2 setup in 2020-2021.

My research activity in the SIDDHARTA-2 experiment:

- ***Monte Carlo simulation***
  - ***Monte Carlo simulations for the SIDDHARTA-2 apparatus, to optimize the critical parameters of the setup, like target size, gas density, detector configuration, degrader size and shielding geometry. The structure and the thickness of the degrader were decided using the Monte Carlo simulations.***
  - ***Monte Carlo simulation for the determination of the experimental efficiencies for the Kaon Luminometer and Kaon Monitor.***
  - ***Monte Carlo simulation to estimate the signal to background ratio for kaonic helium 4 and kaonic hydrogen using different thickness of the degrader.***
  - ***Monte Carlo simulation to estimate the signal of the kaonic lead (9→8) in the HPGe detector.***
- ***Calibration of the Silicon Drift Detectors***
  - ***I was monitoring the detector calibration of the SDDs both in DAΦNE accelerator with SIDDHARTINO setup during the optimization run and in laboratory with the test-setup, being responsible for the calibration of the detectors.***

The AMADEUS initiative

The AMADEUS (Antikaonic Matter At DAΦNE: Experiments with Unraveling Spectroscopy) experiment will investigate the antikaon-nucleon potential in the nuclear environment, through the search of the so-called deeply bound kaonic nuclear states with a dedicated setup to be implemented in the inner region of the KLOE detector at DAΦNE accelerator.

The AMADEUS experiment aims to provide unique quality data of K^- hadronic interactions in light nuclear targets, in order to solve fundamental open questions in the non-perturbative strangeness QCD sector, like the controversial nature of the $\Lambda(1405)$

state, the yield of hyperon formation below threshold, the yield and shape of multi-nucleon K^- absorption, processes which are intimately connected to the possible existence of exotic antikaon multi-nucleon clusters.

As a step 0 of the experiment, AMADEUS exploits the KLOE detector as an active target and the 2004-2005 KLOE collected data were analyzed exploiting K^- absorptions in H, ^{4}He, ^{9}Be and ^{12}C in the setup materials. The investigation of the absorptions of K^- inside the KLOE Drift Chamber was originally motivated by the prediction of the formation of deeply bound kaonic nuclear states. Their binding energies and widths could be determined by studying their decays into hyperons and nucleons. Also intimately connected with the kaon-nucleon potential is the Λ(1405) resonance, of which the still puzzling nature can be investigated within AMADEUS. The study of the KN interaction at low energies is of interest not only for quantifying the meson-baryon potential with strange content, but also because of its impact on models describing the structure of neutron stars. From the analysis of the KLOE 2004-2005, information on both the strength of the K^- binding in nuclei and the in-medium modification of the Σ^* and Λ^* resonances properties can be extracted by analysing, respectively, the $\Lambda/\Sigma - p$, d, t channels and at the resonances decay channels $\Lambda/\Sigma - \pi$

In order to increase the statistics and as an essential interpretation tool, AMADEUS step 1 consisted in the realization of a dedicated pure carbon target, implemented in the central region of the KLOE detector, providing a high statistics sample of pure at-rest K− nuclear interaction. In the summer 2012 a first half cylinder carbon target was built and installed inside the Drift Chamber of KLOE. The target thickness was optimized to have a maximum of stopped kaons (about 24% of generated) without degrading too much the energy of resulting charged particles inside the target material. The experiment was running from October to the end of 2012. The analysis of these data is ongoing; it will provide new insights in the low-energy interactions of charged kaons in the nuclear matter. For the future, other targets are planned to be used compatible with the beam assignment.

My research activity in the AMADEUS experiment:

- ***<u>Data analysis</u>***
  I participate to the data analysis of the 2004-2005 KLOE collected data, being responsible of the analysis of the interactions of the kaons produced at DAFNE collider in the ^{4}He nuclei present in the drift chamber gas and with the ^{12}C nuclei contained in the drift chamber wall of the KLOE detector, generating the Λd final state.

Quantum foundational research:
study of the possible violation of the Pauli exclusion principle

The VIP/VIP2 experiments

The Pauli Exclusion Principle (PEP) is a fundamental principle in physics, for which an intuitive explanation is still missing. The violation of PEP would certainly be related to new physics, beyond the Standard Model.

Although the principle has been spectacularly confirmed by the huge number and accuracy of its predictions, its foundation lies deep in the structure of quantum field theory and has defied all attempts to produce a simple proof. Given its basic standing in quantum theory, it is appropriate to carry out high precision tests of the PEP validity and, indeed, mainly in the last 20 years, several experiments have been performed to search for possible small violations.

Many (if not all) of these experiments are using methods which are not obeying to the so-called Messiah-Greenberg superselection rule, which forbids the change of the symmetry of the state of a stable system. To bypass this rule, the VIP experiment introduces “new” electrons in the system by means of an electric current.

The VIP (VIolation of the Pauli Exclusion Principle) experiment has the goal to either dramatically improve the previous limit on the probability of the violation of the

PEP for electrons, (P < 1.7× 10^{-26} established by Ramberg and Snow: *Experimental limit on a small violation of the Pauli principle*, Phys. Lett. **B 238** (1990) 438) or to find signals from PEP violation, by exploring a region where new theories could allow for the PEP violation.

The experimental method consists in the introduction of "new" electrons into a copper strip, by circulating a current, and in the search for X-rays resulting from the forbidden radiative transition that occurs if some of the "new" electrons are captured by copper atoms and cascade down to the 1s state already filled by two electrons with opposite spins.

The "new" electrons introduced into the copper target have a certain probability to interact with and be captured by copper atoms. In the course of this interaction, the electrons might form a new symmetry state with the electrons of the atom. This process is the reason why the VIP experiment does not violate the Messiah-Greenberg superselection rule, since the current electrons are "new" to the electrons in the atom, i.e. they have no predefined symmetry of the state.

With a certain probability which should be determined by the experiment, the newly formed symmetry state might have a symmetric component and the electron could undergo transitions from the 2p level to the 1s one, with the 1s already occupied by 2 electrons, which transition obviously violates the PEP

The energy of $2p \rightarrow 1s$ transition, into the copper target, would differ from the normal $K\alpha$ transition by about 300 eV (7.729 keV instead of 8.040 keV) providing an unambiguous signal of the PEP violation. The measurement alternates periods without current in the copper strip, in order to evaluate the X-ray background in conditions where no PEP violating transitions are expected to occur, with periods in which current flows in the conductor, thus providing "new" electrons, which might violate PEP. The rather straightforward analysis consists in the evaluation of the statistical significance of the normalized subtraction of the two spectra in the region of interest (if no signal is seen).

The experiment is being performed at the LNGS underground Laboratories, where the X-ray background, generated by cosmic rays, is reduced.

The first VIP setup was realized in 2005, starting from the DEAR setup, reutilizing the CCD (Charge Coupled Devices) as X-ray detectors, and consisted of a copper cylinder, were current was circulated, 4.5 cm in radius, 50 μm thick, 8.8 cm high, surrounded by 16 equally spaced CCDs of type 55. The setup was enclosed in a vacuum chamber, and the CCDs cooled to 165 K by the use of a cryogenic system. The VIP setup was surrounded by layers of copper and lead to shield it against the residual background present inside the LNGS laboratory.

The VIP experiment was installed at LNGS-INFN in Spring 2006 and was taking data until 2010, alternating period with current on (signal) to periods with current off (background). The data analysis resulted in an upper limit for the violation of the PEP of 4.7×10^{-29}.

In 2011 we started to prepare a new version of the setup, VIP2, installed in 2015 at the LNGS-INFN with which we will gain a factor about 100 in the probability of PEP violation in the coming years.

In order to achieve a signal/background increase which will allow a gain of two orders of magnitude for the probability of PEP violation for electrons, we built a new setup with a new target, a new cryogenic system and we use new detectors with timing capability and an active veto system.

As X-ray detectors we use spectroscopic Silicon Drift Detectors (SDDs) which have an even better energy resolution than CCD and provide timing capability which allow to use anti-coincidence provided by an active shielding which would eliminate a large part of the background produced by charged particles coming from the outside the setup.

In 2018 the VIP2 setup was upgraded with new SDDs and shielding, which was completed in 2019 and is presently in data taking.

In 2019 we have extended the scientific program towards a search of PEP violation predicted by Quantum Gravity inspired models, by using a HPGe detector (no current is necessary in this type of study).

The VIP-2 apparatus contains 4 SDD arrays with 2×4 SDDs detectors each (with 8×8 mm^2), mounted close to the Cu target, two on each side. In 2019 the lead and cooper shielding were finalized. The data taking, together with data analysis, are undergoing. Data with 180 Ampere DC current applied to the copper strip was collected together with the data collected without current, representing the background. A new refined procedure for data analysis, considering the electron difusion in bulk-matter process, was realised in 2019. The data analysis resulted in an upper limit for the violation of the PEP of 2.7×10^{-40}.

My research activity in the VIP/VIP2 experiments:

- ***Measurement and data analysis***

  - ***I was involved in all the phases of the experiment, from installation of the experiment in the underground LNGS laboratory to the measurement and data analysis for the experiment. I was monitoring the data taking, detector calibration and the status of the parameters of the setup(pressure, temperature, vacuum, etc.). I participate to the data analysis finalized with the extraction of probability of PEP violation for electrons.***

Frascati, 04.06.2020 Signature