Stored Particles Atomic Physics Research Collaboration

BOOK of ABSTRACTS

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BOOK of Abstracts

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Table of Content

New results from Penning trap experimnets on highly charged ions and (anti)protons

QUINT Wolfgang (GSI,Darmstadt, University of Heidelberg)

We04

Precise measurements of magnetic moments and masses with individual particles in Penning traps have opened opportunities for fundamental tests of physical theories. The determination of the magnetic moment of the electron bound in highly charged ions is a sensitive test of the theory of bound-state quantum electrodynamics in strong fields. At the same time, such precision experiments allow to determine fundamental constants, like the electron mass and the fine-structure constant a. The recent observation of spin flips with a single trapped proton made it possible to measure the proton magnetic moment with unprecedented accuracy. Most recently, the proton and antiproton masses have been compared on the 10-11 level as a test of CPT invariance, and a high-precision comparison of the proton and antiproton magnetic moments can be expected in the near future.

Relativistic theory of the nuclear recoil effect on the bound-electron g factor

SHABAEV Vladimir (St.Petersburg State University)

We05

Fully relativistic theory of the nuclear recoil effect on the g-factor of ions with one valence electron is formulated. It is shown that to the lowest relativistic order this theory leads to an effective operator that can be derived from the Breit equation in presence a homogeneous magnetic field. With the help of the derived formulas the isotope shift of the g factor of Li-like ions is evaluated.

The ALPHATRAP Experiment

WEIGEL Andreas (Max-Planck-Institut für Kernphysik)

We06

The Penning-trap based experiment ALPHATRAP is currently being set up at the Max Planck Institute for Nuclear Physics in Heidelberg. It is the follow-up to the Mainz g-factor experiment, which has performed the most stringent test of quantum electrodynamics (QED) in the regime of strong fields on hydrogen-like 28Si13+ at an uncertainty level of 10−11. ALPHATRAP aims for g-factor measurements on even heavier ions up to hydrogen-, lithium- and boron-like lead, with simultaneously improved accuracy. To achieve this, the ALPHATRAP experiment, consisting of a cryogenic double Penning-trap setup, will be coupled via an ultra-high vacuum beamline to the Heidelberg Electron-Beam Ion Trap, which provides the highly charged ions. In combination with currently conducted bound-state QED calculations, the measurements aim for an independent determination of the fine-structure constant α with high precision. The current status of the project will be presented.

Zeeman splitting in boron-like ions: g-factor and non-linear effects

GLAZOV Dmitry (St. Petersburg State University)

We07

Experimental and theoretical investigations of the g-factor of heavy few-electron ions will serve for stringent tests of bound-state QED in strong nuclear field and for independent determination of the fine structure constant. As an important step towards this goal, the g-factor measurement for the ground and first excited states of boron-like argon is presently performed at GSI (ARTEMIS experiment). It will be sensitive to the second- and third-order effects in magnetic field. We present the most recent theoretical results for the g-factors and the non-linear contributions to the Zeeman splitting for the middle-Z boron-like ions. The electron-structure, QED and nuclear-recoil effects are evaluated in order to deliver the most accurate up-to-date theoretical values.

Quantum gas target

HÖLTKEMEIER Bastian (Universität Heidelberg)

We08

We report on the status of a novel quantum gas target for HITRAP. The target will consist of a dense cloud of Rubidium atoms which are optically trapped at the center of a Recoil Ion Momentum Spectrometer (RIMS). The target allows a precise state preparation such as high lying Rydberg-states or a Bose-Einstein-Condensate.

CRYRING@ESR Project status

LESTINSKY Michael (GSI, Darmstadt)

We09

The former CRYRING was transported from Stockholm to Darmstadt and is being set up at ESR. The ring will serve mainly as test bed for prototyping FAIR technology and for atomic physics research, but also from nuclear physics or materials sciences. This presentation will report on the present CRYRING@ESR project status and explore the first set of planned experiments. Further, the general conditions and expected performance will be discussed.

Laser cooling facility at the SIS100

WINTERS Danyal (GSI, Darmstadt)

We10

At highly-relativistic kinetic energies, well-established cooling methods become either increasingly difficult to implement (electron cooling), or work best for low ion beam intensities (stochastic cooling). By means of laser cooling, ion beams can also be cooled down to very low temperatures and, thus, obtain small longitudinal momentum spreads (dp/p). In addition, the laser cooling force increases at higher velocities. Also, since laser cooling and laser spectroscopy are very similar, high-precision spectroscopy of atomic systems will be possible. For these reasons, a laser cooling facility will be built at the heavy-ion synchrotron SIS100 at FAIR. The setup required for laser cooling can fairly easily be implemented in the accelerator facility, as has been demonstrated at the ESR, and be adapted to the requirements (ion species, beam energies, lasers, diagnostics). The planned laser cooling facility will be presented, and future usage will be discussed.

Staus report APPA cave

BRAEUNING-DEMIAN Angela (GSI and FAIR, Darmstadt)

We11

APPA cave is a multipurpose experimental area which will accommodate single-pass experiments of the HEDgeHOB/WDM, SPARC and BIOMAT collaborations. The cave will have two different beam lines along which more than six different experiments will be installed and operated using relativistic, high intensity beams of protons and heavy ions. The present contribution will present the SPARC/BIOMAT beam line design and the status of the proposed experimental setups.

The High Energy Storage Ring

Dr. PRASUH Dieter (Forschungszentrum Jülich)

We12

The High Energy Storage Ring (HESR) at FAIR in Darmstadt is designed and will be constructed by an international consortium under the leadership of Forschungszentrum Jülich GmbH. It is designed as storage ring for internal target experiments. In the HESR anti-protons as well as ions can be stored in a magnetic rigidity regime between 5 Tm and 50 Tm. Injection of anti-protons or ion takes place at a fixed rigidity of 12 TM from the CR of FAIR. Modes of operation experimental conditions for the different projectiles will be discussed. The status of the project will be presented.

Astrophysics experiments in storage rings

LITVINOV Yury (GSI, Darmstadt)

Th01

Heavy-ion storage rings coupled to radioactive beam facilities offer unparalelled conditions for astro-physics experiments. Two facilities operate now: the Experimental Storage Ring (ESR)/GSI and the experimental Cooler-Storage Ring (CSRe)/IMP. Well-established are mass measurements of exotic nuclei and decay studies of highly-charged radionuclides. Recently, rings were employed for investigations of astrophysical reactions. Proton capture on 94Ru@10 MeV/u was proof-of-principle experiment at ESR addressing reactions relevant for the p-process. In future, with the commissioning of CRYRING@ESR, such reactions will be investigated in the entire Gamow-window. The 20Ne(p,d)19Ne was the first in-ring transfer reaction studied and this reaction will remain one of the flagship experiments at the ESR and CSRe. Research programs at storage rings have proven their high discovery potential, which led to a number of new projects worldwide: TSR@ISOLDE, CRYRING@ESR, R3@RIKEN as well as new complexes FAIR/Germany and HIAF/China.

High Precision X-Ray Spectroscopy at Storage Rings

GAßNER Tobias (GSI, Darmstadt)

Th02

Crystal spectrometers and newly developed magnetic metallic calorimeters are two complementary x-ray detector concepts capable to surpass the limited energy resolution of standard semiconductor detectors. Both detector strategies have been employed at the existing ESR and will be employed at the future CRYRING storage ring to determine QED effects in heavy highly charged ions with highest accuracy. In the presentation the current analysis status of the FOCAL crystal-spectrometer experiment and the first test measurements of the maXs micro-calorimeter will be summarized.

High resolution von Hamos spectrometer for low energy x-rays spectroscopy at CRYRING

BANAS Dariusz (University of Kielce)

Th03

We report on the development of high resolution von Hamos type spectrometer dedicated for low-energy (5-15 keV) x-rays measurement at CRYRING. Thanks to the geometry, the spectrometer will allow simultaneous recording a wide energy range of x-rays with energy resolution in the order of eV. It will be equipped with a segmented-type crystal, which simple preparation procedure allows preserving the spectrometer resolution and spectrometer efficiency.

In order to determine the spectrometer properties, the Monte-Carlo ray-tracing simulations for segmented-type crystals were developed. In the present work the main factors influencing the energy resolution and the efficiency of the spectrometer, such as a crystal radius of curvature, the segment size, a source size, and the spatial resolution of the detector in the dispersion plane will be discussed.

Capture of atomic electron into low-energy continuum states of highly charged ion in relativistic collisions

ANDREEV Oleg (St. Petersburg State University)

Th04

In relativistic ion-atom collisions a variety of basic elementary processes may occurs. Among them one of the most interesting is capture of an atomic electron by the incident ion. Very recently an experiment was performed at the GSI (Darmstadt, Germany) in which relativistic Be-like uranium projectile-ions were colliding with N2 targets. The focus of this experiment was in the investigation of the formation of unbound electrons which move after the collision together with the ion being in the low-energy continuum states of the ion (so called cusp electrons). Such electrons may appear both due to the loss of an initially bound electron by the projectile-ion in the collision with the target (electron loss cusp – ELC) and capture of an electron initially bound in the target by the projectile. (electron capture cusp – ECC). We present a theoretical study of the ECC mechanisms of production of the cusp electrons in relativis-tic ion-atom collision.

Radiation processes in low-energy heavy-ion collisions

KOZHEDUB Yury (GSI, Darmstadt)

Th05

We will report our recent progress in relativistic evaluation of radiation spectra at low-energy heavy-ion collision. Depending on parameters of the system radiation could be both during as well as after collision due to post-collisional relaxation processes. The first one is evaluated within the long-wavelength approximation using our approach for determination of many-electron time-dependent wave function [Tupitsyn et al., PRA 82, 042701 (2010); 85, 032712 (2012)]. For the second one a rather complex analysis of atomic relaxation processes based on known atomic level populations is required [Kozhedub et al., PRA 90, 042709 (2014)]. The method of calculation takes into account the dynamics of all electrons in the system. The role of relativistic effects is investigated.

Low-energy ion collisions

GUMBERIDZE Alexandre (GSI, Darmstadt)

Th06

In the contribution, an experimental program aimed to study low-energy (near-)symmetric ion-atom collisions in storage rings at GSI and FAIR will be presented. One of the main (long-term) goals here is to gain better insight into details of heavy quasi-molecular systems formed in such encounters and thereby access the physics of critical electromagnetic fields. Recent experiments in this regard performed at the experimental storage ring (ESR) devoted in particular to impact parameter sensitive studies of inner shell atomic processes in symmetric collisions of heavy atomic systems will be addressed as well.

Electron-collision spectroscopy of highly charged ions at ESR and CRYRING

SCHIPPERS Stefan (I. Physikalisches Institut, Universität Gießen)

Th07

Recent results from electron-ion collision experiments at heavy-ion strorage rings will be reviewed and perspectives for electron-collision spectroscopy of highly charged ions at ESR and CRYRING will be pointed out.

Experiments with the electron target of the CRYRING

BRANDAU Carsten (University Giessen and GSI, Darmstadt)

Th08

It is planned to install a sheet-beam free electron target at the storage ring CRYRING that operates in transverse collision geometry. Such types of guns were successfully implemented and used in single-pass low-energy electron-ion collision experiments at the University of Giessen since the early 1980s. Although suggested almost 30 years ago for the ESR such a target has never been realized at a storage ring. The target for CRYRING will be based on recent developments at the Universities of Giessen and Frankfurt on a flexible multi-electrode design. The physics opportunities of the target will be discussed and the status of developments will be summarized.

Internal Target at CRYRING

PETRIDIS Nikolaos (GSI, Darmstadt)

Th09

Recent optimization efforts regarding the existing ESR internal target station at GSI lead to the proposal of a new design for future storage ring experiments within the SPARC collaboration. The "SPARC-Target@HESR" technical design report envisages an extremely compact device that is capable of providing target beams featuring a large variety of selectable target parameters, such as target width, density and species. The applicability of the new internal target design "SPARC-Target@HESR" at the experimental environment of the CRYRING facility will be presented in detail. A special emphasis will be given on the demanding vacuum requirements. Different options for the implementation will be discussed.

High accuracy measurements of transition energies in Highly Charged Ions with a Double-Crystal Spectrometer

MACHADO Jorge (LIBPhys-UNL)

Th10

We present our experimental goal using a Double-Crystal Spectrometer (DCS) to measure transition energies in highly charged ions with high accuracy. We aim to extend the accurate transition energy measurements to other ions and species (Ar, Kr, K and S) aiming now an accuracy less than 2 ppm with the improvement of the DCS experimental apparatus, in particular a better control of the crystals temperature and verticality and the implementation of new X-ray detectors. With an accuracy of ppm, this method can be used to probe and test QED effects, provide new and more reliable X-ray standards in the few keV energy region. The experimental setup and the current status of the experiment will be presented focused in the DCS working principle and in the planned measurements and setup updates.

Solution of the time-dependent Dirac equation for a H-like ion exposed to a strong laser field

IVANOVA Irina (St. Petersburg State University)

Th11

Nowadays, laser technologies are rapidly developed and highly charged ions are ones of the most interesting objects that can be studied with intense laser fields. The time-dependent problems including an interaction with intense laser fields attract much attention during the past few years. In this work, a method for the investigation of highly charged ions exposed to an intense laser field is developed and tested on various examples. The time-dependent Dirac equation for a H-like ion in presence of a strong laser field is solved numerically. The method is used for calculations of excitation and ionization probabilities of H-like ions. The interaction with the electromagnetic field is described within the dipole approximation in the length and velocity gauges. Based on the method developed, excitation and ionization probabilities are calculated for various ions in both length and velocity gauges. It is shown that the results obtained in two gauges coincide with each other.

Laser spectroscopy experiments at HITRAP and CRYRING

ANDELKOVIC Zoran (GSI, Darmstadt)

Th12

Precision laser spectroscopy experiments with highly charged ions (HCI) at low energies are foreseen at two facilities at GSI and FAIR – the HITRAP facility and the low-energy storage ring CRYRING. At the SPECTRAP experiment, continuous-wave lasers are used for laser cooling of Mg ions and for precision laser spectroscopy of forbidden transitions in HCI. The planned experiments will increase the precision of the recent successful measurements of ground-state transitions in Bi^{80+} and Bi^{82+} at the ESR by several orders of magnitude and thus enable a very precise test of QED in the strong field regime. At CRYRING the first planned experiments include investigations of polarized ion beams inside of a storage ring. Recently, in an experiment at the ESR, an indication for optical polarization of an ion beam has been observed. CRYRING is an ideal place for further detailed investigations, especially during the shutdown of the GSI accelerator, since suitable ions can be delivered by the local injector. Further experiments include laser-based high-voltage measurements and dielectronic-recombination-assisted laser spectroscopy. An overview of all these experiments will be given.

Spectroscopic investigations in high-Z few-electron ions using the resonant coherent excitation in crystals

BRAEUNING-DEMIAN Angela (GSI and FAIR, Darmstadt)

Fr01

The structure of high-Z few-electron ions bears fundamental information relevant for the predictions of the quantum electrodynamics and relativistic effects in strong fields. The nonperturbative effects introduced by the higher order terms in (αZ) contributing to the self-energy can be successfully tested in such systems. The recent advances reached by theoretical predictions request to be matched by similar experimental data. Experiments pursuing the direct measurement of transition energies in highly-charged ions proved to be difficult and the achieved resolution does not always match the theoretical one. We propose to use the resonant process of coherent excitation of ions traversing the average field created by a crystal target for precise determination of the transition energy in high-Z relativistic ions. The process of resonant coherent excitation of ions is highly efficient and selective and permits the determination of the absolute value of the transition energy. This contribution presents experimental results obtained recently at GSI.

High photon flux narrowband XUV sources for laser spectroscopy of highly-charged ions

ROTHHARDT Jan (HI Jena)

Fr02

We present recent advances in the development of high photon flux XUV sources dedicated to laser spectroscopy of highly-charged ions. A two-step frequency conversion scheme, consisting of second harmonic generation of the driving femtosecond fiber laser in a nonlinear crystal followed by high harmonic generation in a noble gas jet, allows for high conversion efficiency and narrow spectral band-width at the same time. As a result, more than 1013 photons/s within a single harmonic line at ~21.7 eV photon energy have been achieved. At the same time an energy bandwidth as small as ~150 meV was obtained. In future, state-of-the art femtosecond fiber lasers will enable more than 1014 photons/s and an energy bandwidth as small as 10 meV. These novel light sources will enable seminal studies on electronic transitions of highly-charged ions and the live-time of short-lived excited states, thus, providing novel benchmarks for atomic structure theory.

SPARC detectors and polarimetry: New results from PETRA III

WEBER Günther (HI Jena)

Fr03

We present a first experimental study of the polarization transfer in the elastic (Rayleigh) scattering of hard x-rays. At the PETRA III synchrotron facility, nearly 100% linearly polarized 175 keV photons were elastically scattered from a thin gold foil and the polarization properties as well as angular distribution of the scattered x-rays were recorded. Good agreement with state-of-the-art theoretical calculations is found. Moreover, we conclude that the polarization transfer characteristics can serve as a highly sensitive probe of the degree of polarization of the incident x-ray beam.

Helmholz beamline

Dr. BAGNOUD Vincent (GSI, Darmstadt)
KÜHL Thomas (GSI, Darmstadt)

Fr04

The Helmholtz Beamline @ FAIR is a project proposed in cooperation between the Helmholtzzentrum Dresden Rossendorf, the GSI Helmoltzzentrum and the Helmholtzinstitut Jena. The aim of the project is to assure the existence of an adequate state-of-the-art laser facility together with the FAIR facility. The laser facility will in particular combine the needs of the APPA collaboration for combined laser and heavy-ion experiments at the APPA cave and the HESR. Details of the state of planning are given.

Gamma and Laser beam induced nuclear and atomic physics at ELI-NP

BALASCUTA Septimiu (IFIN-HH, Department of ELI-NP)

Fr05

The Extreme Light Infrastructure Nuclear Physics (ELI-NP) is one of the three European high power Laser facilities, planned to become operational in 2018 at IFIN-HH in Romania. We present an overview of the facility and the planned experiments with both 19 MeV Gamma beam (photonuclear reactions, beams of polarized positrons) and the two 10 PW Laser beams (electron-positron pair production, laser wakefield acceleration of electrons, laser driven nuclear reactions, nonlinear Compton scattering of electrons by a laser beam). Two 1 PW laser beams will also be used to study the changes in materials exposed to extreme conditions, and the biological effects of multi-component irradiation. As a long range plan, combined gamma and Laser beams will be used to study the radiation reaction and further QED phenomena.

The Plasma Physics Experiments with Intense Heavy Ion and Proton Beams at FAIR

BLAZEVIC Abel (GSI, Darmstadt)

Fr06

Knowledge of basic physical properties of matter under extreme conditions of high energy density, and in particular, of the so-called warm dense matter (WDM), such as equation-of-state, static and dynamic electrical conductivity and opacity is of fundamental importance for various branches of basic and applied physics. Intense beams of energetic heavy ions provide a unique capability for the high energy density (HED) physics research compared to traditional drivers. Using intense ion beams from FAIR, one can heat macroscopic volumes of matter fairly uniformly and generate this way high-density and high-entropy states. This new approach permits to explore fascinating areas of the phase diagram that are difficult to access by other means.In this paper we discuss various physics and technical issues of the high-energy-density (HED) physics research that is to be carried out by the plasma physics collaborations HEDgeHOB and WDM at FAIR.

Isotope shifts of the energy levels in highly charged ions

ZUBOVA Natalia (St. Petersburg State University)

Fr07

Relativistic calculations of the isotope shifts of energy levels in highly charged ions are performed. The nuclear recoil (mass shift) contributions are calculated by merging the perturbative and large-scale configuration-interaction Dirac-Fock-Sturm (CI-DFS) methods. The nuclear size (field shift) contributions are evaluated by the CI-DFS method including the electron-correlation, Breit, and QED corrections. The nuclear deformation and nuclear polarization corrections to the isotope shifts in Li-like neodymium, thorium, and uranium are also considered. The results of the calculations are compared with the theoretical values obtained with other methods.

Setup of a high-resolution Seya-Namioka-type fluorescence spectrometer for the spectral range between 35 nm and 180 nm for experiments at ion storage rings

REISS Philipp (University of Kassel)

Fr08

A Seya-Namioka type spectrometer for the detection of highly resolved dispersed fluorescence in the wavelength range between 35 nm and 180 nm for experiments at gas- and electron targets and electron coolers at the FAIR facility will be set up. Depending on the experimental requirements, optical reflection gratings with a short focus (f = 1m) for a higher solid angle coverage of the emitted fluorescence and a resolution of $\Delta\lambda \leq 0.3$ nm or a grating with a long focus (f = 3m) for high resolution ($\Delta\lambda \leq 0.1$ nm) will be used. The pursued high resolution will enable the determination of the degree of ionization as well as the radiative states of excited ions via their emitted fluorescence wavelengths and thus help answering a variety of scientific questions. A characterization of the gas target or the longitudinal ion bunch profiles is also possible.

Observation of Coherence in the Time-Reversed Relativistic Photoelectric Effect

TASHENOV Stanislav (Heidelberg University)

Fr09

The photoelectric effect has been studied in the regime of hard x-rays and strong Coulomb fields via its time-reversed process of radiative recombination (RR). In the experiment, the relativistic electrons recombined into the 2p3/2 excited state of hydrogenlike uranium ions, and both the RR x-rays and the subsequently emitted characteristic x-rays were detected in coincidence. This allowed us to observe the coherence between the magnetic substates in a highly charged ion and to identify the contribution of the spin-orbit interaction to the RR process.

Highly charges ions impact, a promising route to exploit the refrigeration power of giant magnetocaloric thin films

TRASSINELLI Martino (CNRS, Sorbonne Universités, UPMC Univ Paris)

Fr10

Modifications of material properties by ion impact have been extensively studied in the last decades. Here we investigate thin film presenting a first-order magneto-structural transition (MnAs) irradiated with slow highly charged ions (Ne9+ of 90 keV). MnAs is one of the more promising candidates for developing magnetic refrigeration since it exhibits giant magnetocaloric effect (GMCE) associated to its phase transition close to room temperature. The practical use of GMCE materials for real refrigerator systems is blocked by the presence of a large thermal hysteresis in the magnetization cycle, which is typical of first-order transition materials. Differently from other means applied previously to reduce the thermal hysteresis, ion collisions induce new defects that act as seeds for the nucleation of one phase with the other during the transition. Consequently, the thermal hysteresis is entirely suppressed whereas other structural and magnetic properties are almost unchanged. In particular, the refrigeration power of MnAs thin film related to GMCE is preserved.

Highly charged ions in search towards the variation of fundamental constants

ORESHKINA Natalia (Max-Planck-Institut für Kernphysik)

Fr11

In the current work, we present theoretical results for optical spectra of Ir17+ as a candidate ion for sensitive spectroscopic tests of the variation of the fine structure constant. We also present the results of calculations and measurements of optical spectra of Nd-like W, Re, Os, Ir, and Pt ions of particular interest for such studies. We infer two possible values for optical M2/E3 and E1 transitions in Ir17+ which have the highest predicted sensitivity to a possible variation of alpha among stable atomic systems.

Ion induced molecular dissociation

SAFVAN C.P. (IUAC, New Delhi)

Fr12

Collisions of highly charged heavy ions with molecules are studied in a wide range of impact energies from MeV down to eV. Collision-induced dissociation is used to measure the lifetimes of multiply charged molecular ions. Dissociative recombination of molecular ions is investigated at an electron cooler in a storage ring. The physics issues addressed are mainly on the kinetics and dynamics of multiply charged molecular dissociation and intramolecular bond formation.

Auger electron yields of metastable Li-like projectile states repopulated by radiative cascades and Auger depletion

BENIS Emmanouil (University of Ioannina)

Sa01

In Auger electron measurements of metastable projectile states, where the spectrometer lies at 0 degrees to the ion beam, the overall detection solid angle varies with the electron emission position complicating the determination of the Auger electron yields. Recently, we published on a treatment of this problem based on a Monte Carlo approach utilizing the SIMION package. Here, we extend our treatment to also include the repopulation of such states by radiative transitions from higher n-states as well as depletion by Auger effects. We make use of theoretical time-dependent results for the 1s2s2p 4,2P states populated in 12 MeV C4+ + He collisions and evaluate the 4P/2P ratio of Auger electron yields, whose observed non-statistical production awaits further resolution.

The magnetic toroidal sector: a broad-band electron-positron pair spectrometer

HAGMANN Siegbert (GSI-Darmstadt)

Sa02

For heavy-ion atom collisions at near-relativistic collision velocities, electron-positron pairs from non-nuclear, atomic processes appear as significant reaction products. The underlying production mechanisms are a central topic of QED in strong fields. In the free-free pair production both leptons, electron and positron, are emitted into the continuum. Calculations on the vector-momentum correlation of electron positron pairs beyond the elementary back-to-back emission in the emitter frame are not available. Experimental benchmark data on the vector momentum correlation of electron positron pairs are highly desirable for elucidation the produc-tion mechanism. We investigate the electron-optical properties of a modified 90 degree magnetic toroidal sector configuration for mapping electrons and positrons suitable for implementation into a storage ring and covering a wide range of emission into the forward hemisphere.

X-ray emissions from the decay of highly charged ions via overlapping resonances

WU Zhongwen (Helmholtz Institute Jena)

Sa03

Angular and polarization properties of x-rays have been investigated for two-step radiative cascades that proceed via intermediate overlapping resonances within the density matrix theory. Special attention has been paid to reveal how the level-splitting of these resonances affect x-ray emissions and, whether the angular and polarization properties of the x-rays can help determine level-splittings in highly charged ions. Detailed computations have been performed for the two-step 1s2p2 Ji = 3/2 -> 1s2s2p J = 1/2, 3/2 + γ1 -> 1s22s Jf =1/2 + γ1 +γ2 cascade of W71+ ions. A considerably strong depolarization effect, associated with increasing level-splitting $\Delta\omega$ within 0.2 a.u. $\approx$ 5.4 eV, has been found for both the angular distribution and the linear polarization of the second-step photon emissions. We therefore suggest that accurate angular distribution and polarization measurements of x-rays could be utilized to determine small level-splittings in highly charged ions.

DESIREE: Double ElectroStatic Ion-Ring ExpEriment

SCHMIDT Henning (Stockholm University)

Sa04

DESIREE at Stockholm University consists of two electrostatic ion-storage rings with a common straight section for merged-beams studies of interactions between positive and negative atomic or molecular ions. The two rings are enclosed in a single cryogenic vacuum enclosure where residual-gas densities of the order of 10^4 cm^{-3} are reached for a temperature of about 13 K.

First results of single-ring experiments on lifetime determinations for metastable bound levels of negative atomic ions have been achieved (E. Bäckström *et al.* Phys. Rev. Lett. **114**, 143003). Preliminary results of cooling studies of molecular and cluster anions are further discussed as are results of mutual neutralization test experiments as well as recent technical developments

First operation of the cryogenic electrostatic storage ring CSR

VON HAHN Robert (Max-Planck-Institut für Kernphysik)

Sa05

In April 2015 the full cryogenic storage ring CSR with a circumference of 35 m was successfully cooled to cryogenic temperatures for the first time. After roughly 3 weeks the experimental vacuum chambers with the electrostatic electrodes achieved temperatures well below 10 K. An injected 60 keV Ar+ beam was immediately successfully stored. By laser detachment life times of negatively charged molecular ions of OH-, Ag2-, Co2-, Co3- could be measured up to values between 1700 s and 2400 s. For the next experimental phase in 2016 injection at 300 keV, 2 K operation, phase space cooling with an electron cooler and electron ion reactions as well as neutral beam collisions are in preparation.

Status of the FISIC project

Prof. VERNHET Dominique (INSP- UMR CNRS 7588- UPMC- Sorbonne Universités)

Sa06

The FISIC (Fast Ion - Slow Ion Collision) experimental program aims to utilize the intense ion beams provided by the SPIRAL2 facility (even also CRYRING@FAIR) in order to address the ion-ion collisions in the hitherto unexplored intermediate regime. Such studies are of fundamental interest as they will allow benchmarking the state-of-the-art atomic collision theories in the regime where most of the current standard approaches cannot really be applied. Furthermore, this regime is particularly interesting, because here cross sections for various atomic processes are of the same order of magnitude, interferences between different channels occur, the multiple processes become important and the ion stopping power is at maximum. An ultimate control on dressed orbitals of the medium-Z projectile and the target ions should provide a breakthrough in the domain. A status report on the advances of the FISIC project will be presented.

Nuclear recoil and vacuum polarization effects on the electronic bound states in supercritical hydrogenlike ions

ALEKSANDROV Ivan (Saint Petersburg State University)

P01

The nuclear recoil and vacuum polarization effects on the electronic bound states in supercritical hydrogen-like ions are considered. In [P. Gärtner et al, Z. Physik, A 300, 143 (1981)] it was shown that the interaction with a point charge in quantum electrodynamics (QED) cannot effectively have the coupling strength of 1 or greater. This statement is revised in the presence of the recoil and vacuum polarization operators of different types. It turned out that these effects significantly change the pattern described previously. This investigation is expected to clarify several fundamental aspects of the modern quantum theory at supercritical regime which can be important for future experiments at the FAIR facilities aimed on tests of QED in supercritical fields.

Inner-shell vacancy production in slow ion-atom collisions

BONDAREV Andrey (St. Petersburg State University)

P02

Inner-shell vacancy production probabilities as well as alignment of atomic shells are calculated for several slow heavy ion-atom collisions. The relativistic effects are analyzed.

Optimization of a gaseous multitube detector for soft X-ray detection

DUMCHEV Mykhailo (Leuphana University Lüneburg)

P03

To proof the QED corrections of the 1s Lamb shift, high precision X-ray spectroscopy of low energetic transitions in high-Z ions is necessary. Since photons will be detected in coincidence with down-charged ions, a time resolution < 50 ns is required. Therefore, a gaseous tube detector has to be designed. To find the optimal values of the tube parameters (voltage, gas mixture/pressure, wire diameter, and anode-cathode distance), the performance of one tube is simulated with Garfield software. Within the simulation the induced signals are computed taking both into account: electron pulse and ion tail. The latter is based on the avalanche creation after the passage of a 10 keV photon through the gas inside the tube. It turns out, that different parameter sets fulfill the requirements in a certain parameter range. Thus, a set for a simple tube construction can be used for the experimental validation. Furthermore, a multitube configuration will allow for a spatial resolution ~ 100 μm.

Detection system for forward emitted XUV photons from relativistic ion beams

HANNEN Volker (Institut für Kernphysik, Uni Münster)

P04

Highly charged heavy ions provide a unique possibility to test atomic structure calculations. We would like to study effects of electron-electron correlations in Be-like krypton via a laser spectroscopy measurement of the fine-structure transition from the metastable 3P0 state. For this purpose the ions are stored at $\beta=0.69$ in the Experimental Storage Ring (ESR) where the transition to the 3P1 state is excited by an anticollinear laser beam, followed by the almost immediate decay to the ground state by emission of 17 nm XUV photons. To collect forward emitted photons a cathode plate with a slit for the ions is moved into the beam. XUV photons hitting the plate produce mostly low energetic secondary electrons. These electrons are guided electromagnetically onto an in vacuum MCP detector. The design and working principle, as well as results of first test measurements with the XUV detection system, will be presented. This work is supported by BMBF under contract number 05P12PMFAE.

Forward-angle electron spectroscopy in heavy-ion atom collisions studied at the ESR

HILLENBRAND Pierre-Michel (GSI, Darmstadt)

P05

In collisions of heavy highly-charged projectile ions with atomic targets, the energy distribution of the emitted electrons is a characteristic observable for the underlying elementary processes. At the experimental storage ring ESR, a dedicated magnetic electron spectrometer was built downstream from the gas-jet target, which enabled the measurement of high-energetic electrons emitted in ion-atom collisions within a small cone in the forward direction. Using this electron spectrometer in combination with detectors for emitted x rays and charge-exchanged projectiles, the study of the collision system U88+ + N2 @ 90 MeV/u revealed three processes resulting in the emission of cusp electrons: electron loss to continuum (ELC), electron capture to continuum (ECC), and radiative electron capture to continuum (RECC). The latter process can be seen as the high-energy endpoint of bremsstrahlung studied in inverse kinematics. Within this study it was shown that each of the three processes is characterized by a unique electron cusp shape.

Electron emission spectra of U28+ ions colliding with gaseous targets

HILLENBRAND Pierre-Michel (GSI, Darmstadt)

P06

Understanding the ionization of multi-electron projectile ions like U28+ colliding with gaseous targets is of fundamental interest. Furthermore it is of particular relevance for the estimation of ion beam lifetimes in the heavy-ion accelerators of FAIR. Differential cross sections for the ionization of U28+ ions colliding with gaseous targets H2, N2, and Xe have been studied at projectile energies of 30 and 50 MeV/u. The experiment was performed at the experimental storage ring ESR, using the magnetic forward-angle electron spectrometer mounted downstream from the supersonic gas-jet target. The energy distribution of electrons emitted under 0° with respect to the projectile beam shows a characteristic cusp shape with an asymmetry, which increases significantly with the target atomic number. Comparison of the experimental data with latest results of continuum-distorted-wave calculations applying relativistic wave-functions for the U28+ projectile are presented.

The APAPES initiative and experimental determination of the 1s2s2p 4P/2P ratio produced in ion-atom collisions

IOANNIS Madesis (University of Crete, Heraklion)

P07

An experimental beamline dedicated to atomic collisions physics research within the APAPES initiative at the 5 MV TANDEM “Demokritos” accelerator in Athens, Greece has been constructed. A zero-degree Auger projectile spectroscopy apparatus composed of a single stage hemispherical spectrometer and a 2-dimensional position sensitive detector combined with a doubly-differentially pumped gas target has been assembled for high-resolution studies of electrons emitted in ion-atom collisions. With this setup a systematic isoelectronic investigation of K-Auger spectra emitted from pre-excited ions in collisions with gas targets is planned. To date, new results include first 0-degree measurements from 12 MeV C4+ + H2, He, Ne, Ar. Results combined with simulation data will lead to a deeper understanding of the importance of cascade feeding in collisions of (1s2s 3S) pre-excited He-like ions with gas targets and elucidate their role in the non-statistical production of excited three-electron states by electron capture.

SiM-X: Silicon microcalorimeters for high-precision X-ray spectroscopy - Status and Perspectives

KRAFT-BERMUTH Saskia (University Giessen)

P08

High-precision X-ray spectroscopy of highly-charged heavy ions is one of the established subjects within the program of SPARC. To improve the precision of such experiments, the detector concept of silicon microcalorimeters, which detect the temperature change of an absorber induced by an incoming photon, is now exploited. Silicon microcalorimeters were successfully applied in several experiments at the ESR at GSI. However, it was found that for application at FAIR further improvements in detector design and performance are mandatory, namely larger detector solid angle, combination of absorbers for high x-ray energies around 50–100 keV with absorbers for low x-ray energies around 5–10 keV, improvement in readout electronics and data acquisition. The contribution will present the design of a new detector array which fulfils these requirements. First components are already under production, the whole detector is expected to be assembled and tested until 2018.

Quantum correlations in recombination processes with highly charged heavy ions

MAIOROVA Anna (St. Petersburg State University)

P09

In the present work we investigate quantum correlations in recombination processes. In particular we consider the radiative recombination of the relativistic electron with bare heavy ion into the 2p3/2 excited state of H-like ion and its subsequent Lyman-α1 (2p3/2 →1s1/2) decay. In our scenario RR photon and subsequently emitted characteristic photon are detected in coincidence. Hence the axial symmetry of the RR-populated 2p3/2 state is removed and the magnetic sublevels of the highly charged ion are populated coherently. We have employed the density matrix approach and relativistic Dirac's theory for description of such coherence between the magnetic substates. We apply our results to test Clauser-Horne-Shimony-Holt's (CHSH) inequality which is one of a family of Bell inequalities.

Electron-positron pair production in low-energy heavy-ion collisions

MALTSEV Ilia (St. Petersburg State University)

P10

A method for calculation of the pair-production process in low-energy heavy-ion collisions is presented. The method is based on the numerical solving of the time-dependent Dirac equation in the monopole approximation. The electron wave functions are expanded in the finite basis set constructed from B-splines employing the dual-kinetic-balance (DKB) technique. The numbers of produced particles and the positron energy distributions are calculated for collisions of bare nuclei at the energies about the Coulomb barrier with the different values of the nuclear charge and the impact parameter. In order to study the role of the spontaneous pair production we also consider the collisions with a modified velocity and with a time delay. The results obtained with the developed method are compared with the previous calculations. The possibility of detection of the spontaneous pair production is discussed.

Ionization energies along beryllium isoelectronic sequence

MALYSHEV Aleksei (St. Petersburg State University)

P11

Ionization energies for the ground state of beryllium-like ions with nuclear charge numbers in the range Z=16-96 are rigorously evaluated. The calculations merge the ab initio QED treatment in the first and second orders of the perturbation theory in the fine-structure constant alpha with the third- and higher-order electron-correlation contributions evaluated within the Breit approximation. The nuclear recoil and nuclear polarization effects are taken into account. The accuracy of the ionization energies obtained has been significantly improved in comparison with previous calculations.

Relativistic calculations of critical distances for homonuclear quasi-molecules

MIRONOVA Darya (St. Petersburg State University)

P12

The ground-state energies of one-electron homonuclear quasi-molecules for the nuclear charge number in the range Z = 1-100 at the „chemical“ distances R = 2/Z (in a.u.) are calculated. The relativistic calculations are performed for both point- and extended-charge nucleus cases using the Dirac-Fock-Sturm approach with the basis functions constructed from the one-center Dirac-Sturm orbitals. The critical distances Rcr, at which the ground-state level reaches the boundary of the negative-energy Dirac continuum, are calculated for homonuclear quasi-molecules in the range: $85 < Z < 100$.

The dependence of the energy resolution of a hemispherical deflection analyzer on the distance h between the exit focal plane and the detection plane

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DIMITRIOU Anastasios (University of Crete Heraklion)

P14

Hemispherical deflector analyzers (HDAs) are equipped with a position sensitive detector (PSD), but geometrical constraints do not always allow for their optimal placement. As a part of the APAPES research initiative and in an effort to improve HDA resolution and PSD energy linearity, we investigate the h-dependence of the energy resolution and line shape in a biased paracentric HDA by installing a piezo-electric motor on the shaft on which the PSD is supported. The setup, at the 5 MV TANDEM of the NCSR “Demokritos”, is primarily dedicated to 0° Auger projectile spectroscopy, performing high resolution studies of electrons emitted from ion-atom collisions.

Influence of dynamical processes on the x-ray spectrum of Fe ions

ORESHKINA Natalia (Max-Planck-Institut für Kernphysik)

P15

In the current work, we present theoretical results for spectra of astrophysically relevant highly charged Fe ions excited by strong x-ray free electron laser pulses. Line intensities and oscillator strengths for the controversial 3C and 3D astrophysically relevant lines in neonlike Fe ions are calculated. High-order electron-correlation effects, quantum electrodynamic contributions and nonlinear dynamical effects were considered. The dynamical effects give a possible resolution of discrepancies of theory and experiment found by recent measurements, which motivates the use of light-matter interaction models also valid for strong light fields in the analysis and interpretation of astrophysical and laboratory spectra.

Relativistic effects in low-energy heavy-ion collisions

Prof. TUPITSYN Ilya (St.Petersburg State University)

P16

In this work we present the results of non-perturbative relativistic calculations of charge-transfer, excitation, ionization and electron-positron pair creation processes in low-energy heavy-ion collisions. To investigate the role of the relativistic effects, the probabilities and cross sections of different processes are calculated for both relativistic and nonrelativistic cases.

Total and single differential electron impact ionization cross-sections

SANTOS Jose Paulo (Universidade Nova de Lisboa)

P17

We present the total and energy differential ionization cross-section expressions for several binary-encounter-Bethe models, and discussed some approximations performed in their earlier versions. Apart from computationally demanding ab initio methods, there are, to the best of our knowledge, no analytical expressions that provide energy differential cross sections for all subshells of atoms and ions, as the ones shown developed by us. The expressions are applied to ionized targets with few-electrons, and to targets with low binding energies in order to enhance the effects caused by the approximations of the various models, and to benchmark the models for these targets.

First measurement of linear polarization of x-ray transitions due to dielectronic recombination in highly charged ions

TASHENOV Stanislav (Heidelberg University)

P18

The linear polarization of x-rays produced by dielectronic recombination into highly charged krypton and xenon ions was measured at an electron beam ion trap using the Compton polarimetry technique. This opens numerous possibilities for diagnostics of anisotropies of hot plasmas. Moreover, it was observed that the polarization of x-rays, following the dielectronic capture populating the 1s 2s2 2p1/21 state, is highly sensitive to the Breit interaction. The experimental results for this transition rule out by 5sigma calculations not taking the Breit interaction into account.

Measuring and modelling anisotropic, polarized x-ray emission from photorecombining $Fe^{18+...24+}$ and $Kr^{28+...34+}$ highly charged ions

TASHENOV Stanislav (Heidelberg University)

P19

We studied the angular distributions of x-rays emitted in the resonant photo-recombination of highly charged iron and krypton ions, resolving dielectronic, trielectronic, and quadroelectronic channels. A tunable electron beam drives these processes, resonantly inducing x-rays registered by two detectors mounted along and perpendicular to the beam axis. The asymmetries extracted comprehensively benchmark full-order atomic calculations, confirming their suitability for the polarization diagnostics of hot plasmas under the premise of inclusion of higher order processes that were neglected in earlier works.

Relativistic calculations of the ionization probabilities for a many-electron ion exposed to a strong laser field

TUMAKOV Dmitriy (St Petersburg State University)

P20

The set of the time-dependent Dirac-Kohn-Sham equations for a many-electron ion exposed to a strong laser field is considered. The "frozen-core" model studied as the first step. Ionization probabilities for a many-electron ion were calculated and compared with ones previously calculated with other techniques.

Injectors for CRYRING

VOROBYEV Gleb (GSI, Darmstadt)

P21

CRYRING storage ring is a part of the Swedish in-kind contribution to the FAIR-project. For the injection from ESR, a new transfer line was designed. All ion species presently accessible in ESR can be transferred to CRYRING. In addition, for ring commissioning and first operation a local injector is available. It provides stand-alone operation from a 40 kV platform where different ion sources can be installed. The beams are focused using electrostatic elements and directed to a RFQ by an analysing magnet. The RFQ has the fixed input energy of 10 keV/u and can accelerate ions which have the $A/q < 4$ to the fixed energy of 300 keV/u. At the same time ions with $A/q > 3$ can be transported but without acceleration. In order to fill acceptance of the ring multi-turn injection scheme will be implemented. Both, beam line calculations and the first results on local injector commissioning will be shown.

Precision high voltage divider for the electron cooler at CRYRING

WINZEN Daniel (Institut für Kernphysik, WWU Münster)

P22

In order to cool ion beams in the heavy ion storage ring CRYRING and thus achieve a low momentum spread, CRYRING features an electron cooler, where the ion beam is superimposed with a mono-energetic electron beam. In earlier measurements of hyperfine transitions in hydrogen- and lithiumlike ions at Experimental Storage Ring (ESR), the limiting uncertainty was the voltage measurement of the electron cooler. We therefore plan to construct a high-precision voltage divider for voltages up to 35 kV which will be similar to the ultrahigh-precision voltage dividers which have been constructed in Münster in cooperation with PTB for use at the KATRIN experiment. The precision of the divider will be in the low ppm range and will, if other sources of systematic uncertainties like e.g. space charge effects are under control, allow for measurement uncertainties in the < 10e-5 region. D. Winzen thanks HGS-HIRe for FAIR for funding his scholarship.

Separation and solid angle correction of the metastable 1s2s2p ^{4}P Auger yield produced in ion-atom collisions using the biased gas cell technique*

ZOUROS Theo (Univ. of Crete, Heraklion)

P23

In zero-degree Auger projectile spectroscopy the long lifetimes (>10-9s) of the 1s2s2p $^4P_{1/2,3/2,5/2}$ metastable states result in their decay along the projectile path towards (and through) the electron spectrometer. Thus, the overall electron detection solid angle varies and correction to the ^4P_J electron yields is needed. Previously, this correction was treated either geometrically or by SIMION simulations. A different approach is adopted here. Separation of the ^4P_J yields produced inside and outside the target can be achieved by applying a relatively small voltage bias to the target gas cell. The ^{4}P component produced inside the cell is thus separated and can be used with corrections to determine the ratio $R=^4P/^2P$ of the production cross sections, where large departures from the expected value of R=2 have been reported, leading to various speculations as to the possible mechanisms involved. Results for 12 MeV C^{4+} collisions with H_2, He, Ne, Ar are presented.

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