GSI

FAIR

ECRIS 24

26th
International Workshop on
Electron Cyclotron Resonance Ion Sources

15.-19. September 2024

Welcome Hotel City Center
Darmstadt
GERMANY

ScanMe

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https://indico.gsi.de/event/17948/overview

TIMETABLE and SESSIONS

SUNDAY 15.09.24	MONDAY 16.09.24	TUESDAY 17.09.24	WEDNESDAY 18.09.24	THURSDAY 19.09.24
18:00-21:00 Registration	8:00 Registration 08:30-9:00 Welcome 9:00-10:30 Oral session MOA	9:00-10:30 Oral session TUA	9:00-10:30 Oral session WEA	9:15 Bus to GSI 10:10-11:40 Oral session THA
	10:30-11:00 Coffee break	10:30-11:00 Coffee break	10:30-10:50 Coffee break	11:40-11:55 Coffee break
	11:00-12:30 Oral session MOB	11:00-12:30 Oral session TUB	10:50-12:20 Oral session WEB	11:55-13:00 Geller Prize & closing remarks
	12:30-14:00 LUNCH	12:30-13:45 LUNCH 13:45-14:00 Group Photo	12:20-13:20 LUNCH	13:00-14:00 LUNCH
	14:00-15:30 Oral session MOC	14:00-15:30 Oral session TUC	13:30 Bus to Frankfurt am Main 14:45-19:00 Excursion 19:00-22:00 Social Dinner	14:00-16:00 GSI/ FAIR Construction site tour 16:00 Bus to hotel or airport
	15:30-16:00 Coffee break	15:30-16:00 Coffee break		
	16:00-17:00 Oral session MOD 17:00-18:30 Poster session MOP	16:00-17:00 Oral session TUD 17:00 IAC MEETING 17:00-18:30 Poster session TUP		

CONFERENCE PRESENTATION

Dear colleague and participant of ECRIS2024,

GSI/FAIR is honored to host the 26th International Workshop on ECR Ion Sources (ECRIS2024) from Sunday the 15th to Thursday the 19th of September at the Welcome Hotel in the city center of Darmstadt, Germany.

The ECRIS workshop deals with the design, construction, development, and operation of ECR ion sources and their components. It focuses on operational experience with existing facilities, achievements in the physics and technology of plasmas and ion sources, progress in the implementation of new projects and modernization of infrastructure, and trends in the proposal, design, and application of ion sources to produce ion beams and their main systems and components.

ECRIS2024 is the 26th in a series of conferences, that dates back to 1978 in Karlsruhe, Germany, and recently took place in Busan, Korea (2016), Catania, Italy (2018), East Lansing, USA (2020), and Gandhinagar, India (2022).

The scientific program covers the following topics of Electron Cyclotron Resonance Ion Sources and related science and technology:

- New development and status reports
- New concepts and next generation
- Fundamental process and plasma studies
- ECR-based charge breeders
- Radioactive ion beams
- Applications and diagnostics
- Beam extraction and transport
- Source modelling

To cover the main topics of the scientific program oral sessions and poster sessions will be included. The number of submitted contributions is 61 including 31 talks and 30 posters. The number of registered participants is 89. The oral presentations will take place from Monday, September 16th to Wednesday, September 18th in the dedicated conference hall of the ***Welcome Hotel***. On Thursday, September 19th, the last session of the workshop including the closing remarks will be held at the main lecture hall of GSI, Darmstadt.

The poster sessions will be held on Monday and Tuesday afternoons in a dedicated conference hall of the ***Welcome Hotel***. The social activities include an excursion to the city of Frankfurt am Main where a cruise of the Main River and a social dinner inside the downtown of Frankfurt city are scheduled. A guided tour of the **GSI** accelerator complex and of the **FAIR** construction site is offered as well.

In recognition of outstanding contributions to the development of ECR Ion Sources and to encourage promising young scientists, Pantechnik - the world leader in commercial ECR ion sources - awards the **"Richard Geller PRIZE"** on the occasion of the workshop.

Seven sponsors financially support the event. The support of the industrial partners is warmly acknowledged and it has been used mainly to reduce the conference fee for students to foster early career contacts in the community and also to the industrial partner.

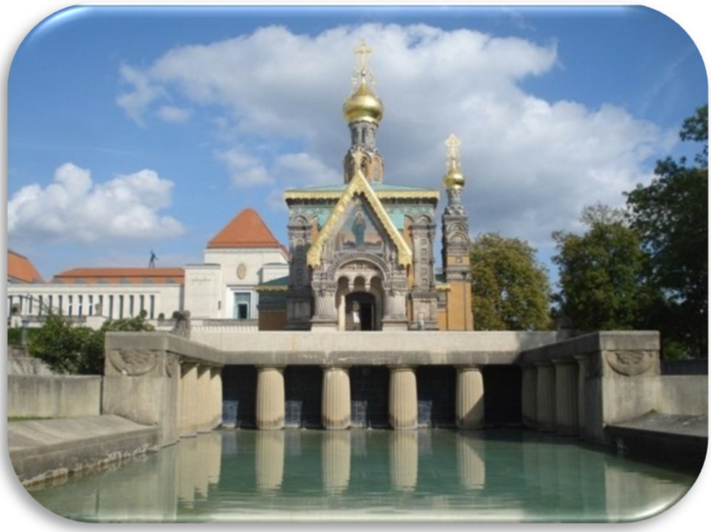
On behalf of the local organizing committee, I would like to welcome you to Darmstadt and I am looking forward to meeting you at ECRIS2024.

Sincerely,

Fabio Maimone
(Chairman of ECRIS2024)

City of Darmstadt

The 26th International Workshop on Electron Cyclotron Resonance Ion Sources welcomes you in the Rhine-Main Metropolitan Region, in the City of Darmstadt, Germany. Darmstadt, also dubbed the "City of Science", is a major center of science institute like GSI/FAIR. It is home to three universities and hosts the European Space Operation Centre (ESOC). It has also a rich cultural heritage. Most notably it was a centre of the Art Nouveau movement ("Jugendstil") and is hence awarded a UNESCO world heritage site, the "Mathildenhöhe".



Mathildenhöhe
Darmstadt’s UNESCO world heritage site

Mathildenhöhe (Ulrich Mathias, Wissenschaftsstadt Darmstadt)

Ernst-Ludwig-Haus (Ulrich Mathias, Wissenschaftsstadt Darmstadt)

Conference Hotel

The workshop takes place in the **"Welcome Hotel"** in the very center of Darmstadt and right beside it's most prominent park, the English style former royal garden "Herrngarten".

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The venue is easy to reach via a direct bus connection between the airport Frankfurt and Darmstadt, the so called "Airliner" or in general by public transport (local transport **rmv.de**, long distance transport **bahn.de**).

About GSI

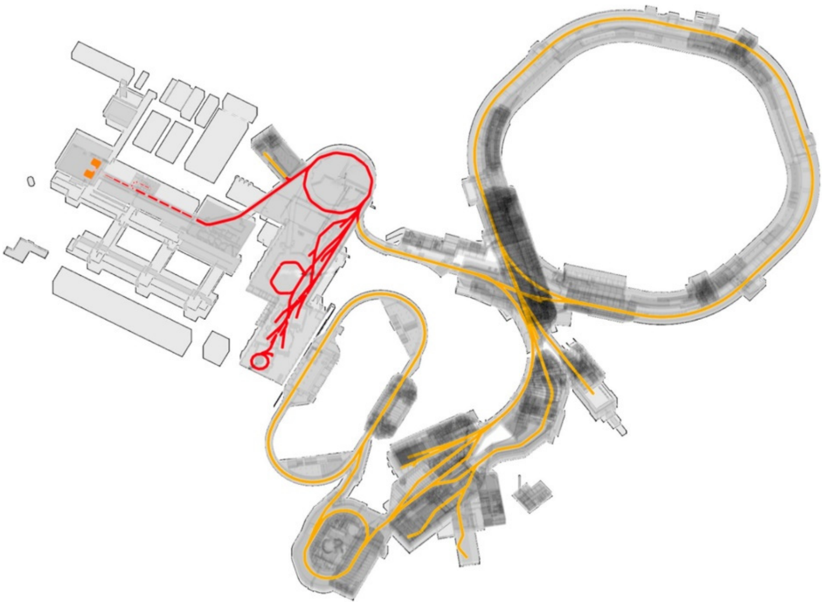
The GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt operates a world-wide leading accelerator facility for research purposes. Shareholders are the German Federal Government with 90%, the State of Hesse with 8%, the State of Rhineland-Palatinate and the Free State of Thuringia with 1% each. They are represented in the GSI supervisory board by the Federal Ministry of Education and Research and the respective state ministries. GSI is a member of the Helmholtz Association, Germany's largest research organization.

About FAIR — Facility for Antiproton and Ion Research

At GSI, FAIR is currently being built, an international accelerator facility for the research with antiprotons and ions which is being developed and constructed in cooperation with international partners. It is one of the world's largest construction projects for international cutting-edge research. The FAIR project was initiated by the scientific community and researchers of GSI. The GSI accelerators will become part of the future FAIR facility and serve as the first acceleration stage.

For the realization of FAIR the FAIR GmbH, an international company under German law, was founded. The shareholders of FAIR come from nine countries: Finland, France, Germany, India, Poland, Romania, Russia, Slovenia, Sweden. The United Kingdom is associated. The Czech Republic is aspirant partner.

The FAIR GmbH has about 60 employees. The GSI GmbH is the German shareholder and also the main shareholder of the international FAIR GmbH. GSI is responsible for the development, production and testing of substantial components of the FAIR accelerator facility and the experiment setups. The efficient cooperation of FAIR and GSI is enabled by the joint organization of both GmbHs under one Management Board.



Committees

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Paola Lindenberg	GSI	Germany
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JACoW Editorial Team (JET)

Raphael Müller	GSI	Germany
Volker RW Schaa	GSI	Germany

GELLER PRIZE

In recognition of outstanding contributions to the development of ECR Ion Sources and to encourage promising young scientists, PANTECHNIK - the world leader in commercial ECR ion sources - awards the "Richard Geller PRIZE" on the occasion of the workshop.
This prize will be awarded for the seventh time and it was established by Pantechnik 16 years ago, during the 18th ECRIS Workshop in Chicago (USA, 2008).

The members of the Award Committee are:

- Benoit Geller (ILEMs ,France)
- Sudhirsinh Vala (IPR, India)
- Olli Tarvainen (STFC, UK)
- Guillaume Machicoane (FRIB/MSU, USA)
- Serge Della Negra (IJClab, France)
- Liangting Sun (IMP, China)

SOCIAL EVENTS

Welcome Reception



The welcome reception will take place on Sunday the 15th at 18:00 at the Welcome Hotel.

Excursion and conference dinner

The social activities include an excursion to the city of Frankfurt am Main. On Wednesday the 18th after lunch the participants will be taken by bus to Frankfurt´s downtown of the city near the Main river. The cruise of the river will allow the participants to get a sightseeing tour of the city. The river cruise on the Main is a great way to discover the city and the most important sights along the river.


The social dinner will be held in a restaurant inside the downtown of Frankfurt city after the conference excursion.




Visit of GSI/FAIR



On Thursday the 19th, a guided tour of GSI/FAIR construction site will take place. The Thursday conference session will take place at GSI/FAIR. After the session, lunch will be offered at the canteen of GSI before starting the tour of the laboratory.

Visit of Heidelberg and the Heidelberg Ion Beam Therapy Center (HIT)

On Friday the 20th a visit to the city of Heidelberg together with the Heidelberg Ion Beam Therapy Center will be offered. The participants interested in the visit can receive upon request the necessary information for traveling to Heidelberg and to Heidelberg Ion Beam Therapy Center (HIT) on their own by using public transportation.


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Table of Abstracts

16 Sep – Mon

16-Sep-24 08:30 – 09:00	Welcome Hotel Darmstadt — Main Hall
MOW — Conference Welcome	

MOW1 08:30 15
Welcome and Opening of ECRIS'24
Fabio Maimone *(GSI)*
Welcome to ECRIS 2024 by Fabio Maimone

MOW2 08:45 15
Welcome by the Head of the Accelerator Division of GSI
Ralph Aßmann *(GSI)*
Welcome by the Head of the Accelerator Division of GSI

16-Sep-24 09:00 – 10:30	Welcome Hotel Darmstadt — Main Hall
MOA — Monday Oral Session MC1 **Chair:** T. Thuillier	

MOA1 09:00 30
High intensity highly charged ion beams production and operation at IMP
Liangting Sun*, Yucheng Feng, Jindou Ma, Enmin Mei, Jibo Li, Libin Li, Lixuan Li, Wang Lu, Xianjin Ou, Cheng Qian, Beimin Wu, Wei Wu, Wenhui Zhang, Xuezhen Zhang, Hongwei Zhao, Shijun Zheng, Li Zhu (IMP/CAS)*
Xinyu Wang (PSI)
Charged by the existing operation facility HIRFL and HIAF one of the next generation heavy ion facilities under construction, high intensity high-charge state heavy ion beams production is in the high priority of research and development. For this purpose, several high performance ECR ion sources have been successively developed and put in routine operation. The recently developed FECR or the First 4th generation ECR ion source has employed the cutting-edge technologies for the development of a hybrid superconducting magnet using Nb_3Sn and NbTi superconductors. Operating at 28-45 GHz, FECR will give its first plasma and intense beam production. Other than ion sources development, new technologies development and new insights into high performance ECR ion source have led to increasingly ion beam intensities increase in both cw or pulsed modes. In this talk, high performance ion source development will be presented. A general review of the recent high intensity ion beam production progress at IMP and the routine operation for heavy ion accelerators will be made.

MOA2 09:30 30
Operation and development of the 28 GHz electron cyclotron resonance (ECR) ion source at the facility for Rare Isotope Beams (FRIB)
Guillaume Machicoane*, Randall Rencsok, Larry Tobos (MSU)*
Haoyu Cheng, Junwei Guo (FRIB/MSU)
FRIB has now been in operations for over 2 years and deliver beam to the nuclear physics users with high reliability and high efficiency. Two ECR ion sources are used to produce a high charge state heavy ion beam including a 28 GHz capable, superconducting ECR that has been used for the scientific program since the beginning of 2023. Central to the performance of the FRIB accelerator are a superconducting linac and a charge stripping system allowing the primary beam to reach energies above 200 MeV/u and a beam power

on the fragmentation target above 10 kW with only a few tens of microamperes required from the ECR ion source. This beam power was achieved for many primary beams including Uranium and has been used routinely for experiments over the past year. FRIB plan to increase the beam power available to users in steps from 20 kW next year and ultimately up to 400 kW. This presentation goes over the operation of the ECR ion sources at FRIB with emphasis on the 28 GHz ECR ion source including solid beam production and plan for intensity ramp up using our 10 kW 28 GHz gyrotron and operation of the superconducting magnet. Finally plans for a second and third superconducting ion source are presented.

MOA3
10:00 30

Development towards intense uranium ion beam production of the RIKEN 28 GHz SC-ECRIS

***Glynnis Mae Saquilayan**, Yoshihide Higurashi, Osamu Kamigaito, Takashi Nagatomo, Jun-ichi Ohnishi (RIKEN Nishina Center)*

High intensity Uranium $^{238}U^{35+}$ ion beams are produced in the 28 GHz superconducting electron cyclotron resonance ion source(SC-ECRIS) and accelerated to high energies in the Radioactive Isotope Beam Factory (RIBF) at RIKEN. We report the current progress of the SC-ECRIS. Intense beam operation of U^{35+} was made possible through the development of high temperature ovens with optimized consumption rates of more than 10 mg/h and beam intensities reaching up to 250 eμA. With efforts toward realizing even higher beam intensities, it is now more important to optimize beam optics and minimize losses in the accelerator. This has stressed the study of emittance size and its growth factors. Measurement using a slit-collector type emittance monitor showed beam emittances that increase proportionally with the extraction current. For beam currents of 100 to 150 eμA, the beam emittances had minimal variation and remain at 0.15 π·mm·mrad for an extraction current of 5.5 mA. Differences between the normalized horizontal and vertical rms emittances were observed and horizontal emittances tend to be lower and less affected by beamline components. Using measured horizontal emittances coupled with a reference model calculation of space charge induced beam emittances, the $^{238}U^{35+}$ beam emittance ε_0 defined by the ion source was estimated. A systematic study using the calculated ϵ_0 to understand its correlation between the ECR parameters and magnetic field strength is currently ongoing.

16-Sep-24 11:00 – 12:30	Welcome Hotel Darmstadt — Main Hall

MOB — Monday Oral Session MC1

Chair: David Mascali

MOB1 11:00 30

GANIL cyclotron ion sources: optimisation for operation

Mickael Dubois, *Stéphane Hormigos, Nicolas Lechartier, Frederic Lemagnen, Vincent Metayer, Benoit Osmond (GANIL)*

The GANIL (Grand Accélérateur National d'Ions Lourds) in Caen has been producing and accelerating stable and radioactive ion beams for nuclear physics, atomic physics, radiobiology and materials irradiation since 1982.

On cyclotrons facility, two ion sources (ECR4 and ECR4M) are used to produce around 4.000 hours per year of gaseous and metallic beams. Recently, studies have been carried out to find ways of optimizing beam characteristics (stability, intensities).

One of these involves improving the long-term stability of the beam, which is an important parameter for tuning the accelerator and for physics experiments. At the same time, this improved stability will also reduce the need of on-call interventions for ion source experts. Other studies and tests have been carried out to increase the intensity and/or stability of the metal beams by adapting the injection of the ion source on ECR4/4M. Depending on the configuration, the gain shall be up to a factor of 2 on the charge state required for acceleration, and stability has also been improved compared to previous one. Some details and results will be presented.

MOB2 11:30 30

ECRIS operation and developments at TRIUMF

Friedhelm Ames, *Joseph Adegun, Christopher Charles, Keerthi Jayamanna, Oliver Kester, Brad Schultz (TRIUMF)*

Rare isotope beams are used at the ISAC facility at TRIUMF for studies mainly in nuclear and astrophysics, but also for applications ranging from material science to medicine. The isotopes are produced via the ISOL technique and ionized via a set of different ion sources depending on the application. In cases where highly charged ions are needed, charge state breeding is done with a 14.5 GHz PHOENIX ECR ion source from PANTECHNIK. The source has been operational for more than a decade providing a wide range of ions from Na to U at A/Q <7 for post-acceleration. A second ECR ion source, a SUPERNANOGAN also from PANTECHNIK is used to provide highly charged ions from stable isotopes either for set-up and calibration for the rare isotope beams or for nuclear reaction studies with stable ions. The presentation will give a summary of results and will describe the challenges and improvements to the original sources. For the charge state breeding this is mainly increasing the efficiency and the purity of the delivered beams. In the case of the SUPERNANOGAN special emphasis is put on operational aspects to cover a wide range of elements and easy switchover. The latest in this series of improvements is the implementation of two frequency plasma heating in both ion sources.

MOB3 12:00 30

Ion source upgrades at MedAustron ion therapy center

Nadia Gambino, *Greta Guidoboni, Matthias Kausel, Clemens Maderböck, Szymon Myalski, Valeria Rizzoglio, Claus Schmitzer (MedAustron)*
Liviu Penescu (Abstract Landscapes)

MedAustron is a synchrotron-based cancer therapy center providing proton and carbon ion beams in an energy range of 62–252 MeV/u and of 120–400 MeV/u, respectively. The facility has three clinical irradiation rooms, among which horizontal and vertical beam lines as well as a proton gantry are available for treatment. A fourth irradiation room is dedicated to non-clinical research and will additionally provide helium ion beams in the near future. The injector features three identical ECRIS operated at 14.5 GHz, two of which are used for proton and carbon ion beam production. The third ion source is used for helium beam generation as well as a test bench for future source upgrades. One of the latest upgrades, rolled-out clinically, is the switch of the carbon ion source from continuous wave operation to pulsed mode operation. In this work we present the main commissioning results obtained in pulsed mode and the beam properties measured up to the irradiation rooms. The results of ongoing source upgrade activities, for future potential clinical use, concerning the use of Double Frequency Heating mode for the proton source, improving the overall accelerator performances, will also be discussed.

16-Sep-24 14:00 – 15:30	Welcome Hotel Darmstadt — Main Hall

MOC — Monday Oral Session MC1

Chair: Alessio Galatá

MOC1
14:00 30

Recent achievements in the production of metallic ion beams with the CAPRICE ECRIS at GSI

***Alexander Andreev**, Michael Galonska, Ralph Hollinger, Jan Maeder, Fabio Maimone (GSI)*

The GSI CAPRICE Electron Cyclotron Resonance Ion Source (ECRIS) provides highly-charged ion beams for various experiments at GSI, enabling the delivery of continuous wave (CW) metallic ion beams with low material consumption, which is crucial for producing high charge state ion beams from rare or extremely rare isotopes such as 48Ca. These metallic beams are produced utilizing the thermal evaporation technique by resistively heated ovens. Due to the research groups' demand for higher beam intensities, increased ion currents of higher charge states are now necessary from the CAPRICE ECRIS.
A test campaign was conducted to establish and improve the production of high charge states of enriched ^{54}Cr and ^{55}Mn ion beams. During the tests, plasma images were captured using a CCD camera to support the operation and enable real-time monitoring of the material consumption. Additionally, a hot screen was used to protect the ceramic insulators in the extraction system from metal deposition, thereby improving the operational stability of the ECRIS. The application of an optical emission spectroscopy to monitor the stability of metallic ion beams during the operation with the resistively heated ovens was also investigated. This contribution presents the operational experience, the intensities and stability achieved for the aforementioned elements. In addition, an update on a recent improvement involving a specialized oven preparation stand for better conditioning of the ovens is given.

MOC2
14:30 30

A novel inductive oven design for the production of high current, metal ion beams

***Damon Todd**, Janilee Benitez (LBNL)*

Essential to the proposed search for element 120 at LBNL's 88-Inch Cyclotron is the continual delivery of over a particle microamp of ^{50}Ti^{12+} for weeks-long campaigns spanning many months. The fully-superconducting ECR ion source VENUS will be the injector source for these runs, and we have developed a new inductive oven design that can survive VENUS' high magnetic fields while injecting metallic gas into the plasma with high efficiency. The new oven employs a vertical susceptor to permit use with metals that melt before outgassing sufficiently, while also allowing a rotation of the oven's material exit toward the plasma center for better conversion efficiency to the produced beam. The performance of VENUS with this oven has been outstanding: as reported here, 282 MeV ^{50}Ti^{12+} beams with stable currents between 1.0 and 1.5 pμA have been delivered for superheavy element searches over multiple ten-day runs.

MOC3 15:00 30

Intense metallic ion beams production with inductive heating oven at IMP

***Wang Lu**, Yucheng Feng, Hongyi Ma, Libin Li, Lixuan Li, Cheng Qian, Liangting Sun, Xuezhen Zhang, Hongwei Zhao (IMP/CAS)*

Since the development of inductive heating oven in 2019, several intense highly charged metallic ion beams have been produced for different requirements at IMP (Institute of Modern Physics). According to the material characteristics, we used different forms of metal materials, including metal elements (Cr, Mn, Ni, Fe), oxides (UO_2), fluoride or iodide (ZrF_4, SrF_2, CsI), etc. Detail experiments setup and testing results will be presented in this contribution.

16-Sep-24 16:00 – 17:00	Welcome Hotel Darmstadt — Main Hall

MOD — Monday Oral Session MC1 & MC7
Chair: Janilee Benitez

MOD1
16:00 30

Development of deuterium-deuterium compact neutron source

Andoni Perez, *Iñigo Arredondo, Victor Etxebarria, Joaquin Portilla (UPV-EHU) Javier Praena, Andrés Roldán (UGR) Jorge Feuchtwanger (Ikerbasque)*

In the present work, we will present the status of the deuterium-deuterium (D-D) neutron source that is being developed in collaboration between the University of Granada and the University of the Basque Country (Spain).

Our neutron source consists of an ECR ion source which accelerates a deuteron beam towards a deuterated target. The ionization to achieve the deuterium plasma is achieved by radiating the cylindrical ERC plasma chamber with a magnetron 2.45 GHz signal and an 875 G magnetic field generated by 6 NdFeB magnets located around the plasma chamber. Moreover, a cylindrical alumina RF window is used to keep the vacuum status from the ambient pressure condition inside the WR340 and helping the plasma to ignite.

Once the plasma is generated, the deuterons are extracted from the plasma chamber using a Pierce electrode geometry and three other electrostatic lenses, fixed to different negative potentials. The beam is accelerated towards copper target disk with a deuterated titanium mesh fixed to –100 kV which generates the desired neutron radiation.

There are several applications of D-D neutron sources across scientific and industrial domains. In case of University of Granada and its deep relation with IFMIF-DONES neutron source, it is worthy to mention that we plan to carry out experiments for determining the cross-sections of relevant isotopes in the studies of IFMIF-DONES to a better simulation of the behaviour of such material under high neutron flux irradiation.

MOD2
16:30 30

Characterization of the ECR ion source LEGIS extraction system and its low energy beam transport line at Legnaro National Laboratories Extraction System

Giada Rachele Mascali *(SBAI) Luca Bellan, Osvaldo Carletto, Michele Comunian, Paolo Francescon, Alessio Galatà, Carmelo Sebastiano Gallo, Denis Martini (INFN/LNL)*

At INFN-Legnaro National Laboratories the heavy ions accelerator complex is fed with beams produced by a permanent magnet ECR source called LEGIS (LEGnaro ecrIS). Although suitable intensities and charge states to fulfil the requests of the users are normally guaranteed, the first part of the Low Energy Beam Transport line (LEBT) downstream of the ion source suffers from non-negligible losses and a lack of scalability when switching between ions with different mass-to-charge ratios, thus leading to a machine preparation time longer than would be desirable. These criticalities called for a deep characterization of the beam coming out from the ion source, especially in the case of high charge states heavy ions production, normally showing the lowest intensities. This contribution describes the numerical studies performed on the extraction system of the LEGIS source and its LEBT. The physics case used is a $^{208}Pb^{31+}$ beam produced for a nuclear physics experiment in fall 2022. As will be shown, the results shed light on the reasons for the bad reproducibility and transmission, mostly due to aberrations induced on the extracted beam by the first optical elements.

16-Sep-24 17:00 – 18:30	Welcome Hotel Darmstadt — Galileo Hall
MOP — Monday Poster Session	

MOP01 **Characterization of the 2.45 GHz DREEBIT ECRIS via optical spectroscopy**

__Maria Molodtsova__, Alexandra Philipp, Erik Ritter (DREEBIT GmbH)

ECR ion sources are widely used to provide ions for various experimental setups. DREEBIT GmbH aims to industrialize this type of ion source technology for efficient and reliable use in, e. g., hadron cancer therapy as well as ion implantation of semiconductors. Our goal is to build table-top sized ion sources which can easily be handled as part of a larger machine such as a particle accelerator or target irradiation facility, thereby fulfilling high requirements on beam current, quality, stability as well as reproducibility in serial production. To achieve this, we have already optimized the microwave injection system and magnetic plasma confinement by introducing a simple method to allow for injection of circularly polarized waves and adjusted the magnetic field distribution which led to an 80 % increase of beam current. In the present work, we show how optical emission spectroscopy was used to gain deeper information about the plasma of this specific type of ion source, independent from its ion extraction system. The plasma characterization includes studies of the electron energy distribution and the density of atomic and molecular hydrogen showing that the previous design changes of introducing circularly polarized microwaves and optimizing the magnetic field distribution have led to a well-optimized ECR ion source concerning plasma heating and proton production inside the plasma, indicating how the source performance can be enhanced in further steps.

MOP02 **Intense pulsed uranium ion beams production with ECRISs**

__Lixuan Li__, Yucheng Feng, Denis Hitz, Jibo Li, Wang Lu, Hongyi Ma, Jindou Ma, Liangting Sun, Wenhui Zhang, Hongwei Zhao (IMP/CAS)

Intense pulsed uranium ion beam production is essential for heavy ion accelerators (especially for synchrotrons) in operation and those under construction. Although metallic beam production is tricky, based on our earlier study, intense uranium beams can be expected when operating a electron cyclotron resonance (ECR) ion source especially in afterglow mode. In this study, we aim to produce intense uranium beams with LECR4 and SECRAL-II (Superconducting ECR ion source with Advanced design in Lanzhou No. II) ion sources in afterglow modes. The experimental results will be reported in this presentation.

MOP03 **ALISES II source is still alive**

__Olivier Delferriere__ (CEA-IRFU) Augustin Dubois, Yannick Gauthier, Yannick Sauce, Olivier Tuske (CEA)

Developments of ECR intense light ion sources is an important research axis of the Laboratory of Study and Development of Accelerator at CEA-Saclay. Starting from the SILHI proton source in the 90's to inject the IPHI accelerator, several SILHI-type sources have been realized and installed for high intensity proton or deuteron accelerators for international projects like IFMIF, FAIR or SPIRAL2. From 2011, we started new R&D program on high intensity ECR compact ion sources with the ALISES source family.

The results obtained with the first ALISES source prototype gave us the main goals for the design of ALISES II source that runs several months on our 50 kV test bench BETSI and was dismounted at the end of 2016 to upgrade the test bench to 100 kV. But this source was never reinstalled and has been replaced by the ALISES III sources that runs on BETSI up to now. Recently, ALISES II ion source and its equipment is reassembled to be restarted on BETSI for beam characterization before sending it to MIRROTRON factory in Hungary as injector of proton for neutron beam facility.
This paper describes the setup on BETSI and proton beam characteristics obtained by emittance measurements, spatial species proportion analysis with Wien filter and current optimization. Installation at MIRROTRON factory is also reported.

MOP04 ALISES 3 ion source in various configuration along the year

Olivier Tuske, *Augustin Dubois, Yannick Gauthier, Yannick Sauce (CEA) Olivier Delferriere (CEA-IRFU)*

ALISES 3 is a very compact light ion source that has been developed at CEA Saclay in 2018. The easy maintenance procedure of this source allowed us to test many different configurations. On the BETSI test bench equipped with an single Alisson Scanner and a pair a solenoid/deviator, we studied the extraction energy influence, we changed the number of electrodes in order to extract different kind of ions other than protons. This paper will describe briefly the ALISES 3 ion source and will present some results that we gathered in a year.

MOP05 Development of a 100 mA-class CW microwave ion source for industrial accelerators

Ryu Murase, *Yukio Mikami, Hirohiko Murata, Nobuaki Takahashi, Kazuhiro Yokoyama (SHI)*

Industrial accelerators are currently employed in a multitude of fields, including semiconductor manufacturing and medicine. In recent years, there has been a growing demand to enhance the irradiation throughput of industrial accelerators, which necessitates the development of high-current ion sources. In this study, we developed a 2.45 GHz off-resonance 100 mA-class CW microwave ion source that can be integrated into industrial accelerators. The design was optimized for proton beam generation. The plasma chamber and the matching section, which is responsible for matching the impedance of the waveguide and the plasma chamber, were designed using a combination of an analytical approach and finite element electromagnetic field analysis. The electromagnets for generating the off-resonance magnetic field to increase the plasma density were designed using finite element magnetostatic field calculations. The design of the single-hole, three-electrode beam extraction system, which operates in acceleration-deceleration mode, was performed using beam orbit calculations that take into account space-charge effects. The design and fabrication have been completed, and beam tests are now underway. In the presentation, in addition to the design of the ion source, we will also report on the preliminary results that were obtained in the beam test.

MOP06 **Performance of the hybrid ECR ion source development at IMP**

Cheng Qian, Liangting Sun *Xing Fang, Yucheng Feng, Jiaqing Li, Libin Li, Wang Lu, Hongyi Ma, Jindou Ma, Zhang Peng, Xudong Wang, Tongjun Yang, Wenhui Zhang, Shijun Zheng, Li Zhu (IMP/CAS)*

Highly charged ion beams have wide applications in fundamental sciences such as nuclear physics and atomic and molecular physics, as well as in applied industries including heavy ion cancer therapy and semiconductor processing. The Electron Cyclotron Resonance (ECR) ion source is one of the most effective devices for producing highly charged ion beams. Based on the requirement for a relatively simple structure and high performance ECR ion source, a Hybrid superconducting Electron Cyclotron Resonance ion source Advanced in Lanzhou (HECRAL) has been designed and constructed at the Institute of Modern Physics (IMP). The magnetic confinement of the ion source is realized by the axial mirror field provided by four superconducting solenoids while the radial hexapole magnetic field supplied by non-Halbach hexapole permanent magnet. The axial injection and extraction magnetic fields reach 3.4 T and 1.7 T, respectively. The radial field at the plasma chamber wall of a 100 mm inner diameter is above 1.4 T. This paper will present a detailed magnet design. The ion source was commissioned and operated at a frequency of 18 GHz with 3 kW power, approaching the performance of the Superconducting Electron Cyclotron Resonance ion source with Advanced design in Lanzhou (SECRAL) operating at the same frequency. Several high intensity high charge state ion beams have been produced, such as 723 eμA O^{7+}, 70 eμA Ar^{16+}, 95 eμA Kr^{26+}, 21 eμA Xe^{35+}, 120 eμA Bi^{33+}, and 88 eμA U^{37+}, and so on.

MOP07 **Use of a 2.45 GHz ECR ion source for the Neutron Target Demonstrator project**

Stephane Melanson, *Anand George, Morgan Dehnel (Dehnel, Inc.)*

D-Pace has licensed a 2.45 GHz ECR ion source from Neutron Therapeutics. The ion source will be used for the Neutron Target Demonstrator project at Los Alamos National Laboratory where 10 mA of singly charge krypton ions at 50 keV are required with a normalized 4-RMS emittance of less than 1 mm·mrad. The goal of the project is to create a reverse kinematics neutron capture reaction with ^{84}Kr ions. Due to the high radiation environment that the ion source will be subjected to, a solid state microwave power supply will be used instead of the traditional magnetron for the experiment. The main advantage of the solid state power supply is that the output is transmitted by a coax cable instead of a waveguide, so the power supply can be located a long distance away from the ion source without the need for a complicated and expensive waveguide. The other advantage of the solid state device is that the frequency can be varied from 2.4 GHz to 2.5 GHz. This gives the operator an extra degree of freedom for tuning the ion source and also allows for the use of permanent magnets instead of solenoids while still having the ability to tune the ECR condition. We present how the frequency variation affects the beam parameters with both the solenoid and the permanent magnet versions of the ion source.

MOP08 **Non-intrusive plasma state detection using machine learning**

Ander Fernández-Rua, *Iñigo Arredondo, Raquel Justo, Pello Usabiaga (University of the Basque Country) Jorge Feuchtwanger (Ikerbasque)*

n this paper we present the methodology used to acquire the data needed to obtain and train a neural network that will be used in an ECR source to infer the state of the plasma. All the data is the combination of the control signals and a set of non-intrusive measurements that can be accessed during normal operation.

For this purpose, machine learning techniques are explored. First, a set of characterisation experiments are carried out in which the state of the plasma is detected for different operating conditions that are fed to a clustering algorithm. Second, a supervised learning paradigm is adopted to train a neural network that is capable of determining the state of the plasma at different working states. The variables that are controlled are: the input RF power and gas flow, the non-intrusive measurements that are acquired are: transmitted and reflected RF power and a ccd camera is used to measure the relative luminosity of the plasma. Based on these variables the state of the plasma is determined. This methodology has been applied to the low-power ECR source in which low-density hydrogen plasmas are generated at the IZPILab laboratory of the University of the Basque Country.

MOP09 **Status report on 60 GHz ECRIS activity**

Thomas Andre, *Julien Angot, Andrea Cernuschi, Pierre-Olivier Dumont, Etienne Labussière, Christophe Peaucelle, Patrick Sole, Thomas Thuillier, Olivier Zimmermann (LPSC) Maud Baylac (CNRS – LPSC) François Debray (LNCMI)*

SEISM (Sixty gigahErtz Ion Source using Megawatt magnets) is an electron cyclotron resonance ion source source operating at the frequency of 60 GHz using a gyrotron producing high intensity HF pulse (up to 1 ms/300 kW/2 Hz). The prototype is based on an axial cusp magnetic geometry using polyhelix coils (installed at the LNCMI facility in Grenoble) generating a closed ECR surface at 2.1 T.

Since 2019 and the restart of the project, several experimental campaigns were carried out using oxygen support gas. Beam production was studied using the setting of the source aiming to reproduce the ion current densities of 1 A/cm^2 previously measured. Set up and recent experimental results, will be presented. Furthermore, in the frame of the PACIFICS project (funded by French National Research Agency under the Equipex Program), a new 60 GHz ion source will be built, where polyhelix will be replaced by superconducting coils and the source will be installed at LPSC for easier availability. A new extraction system will be built in order to transform the observed high current density into a target ion beam intensity of $\sim$100 mA.

This paper will present a preliminary study of the new extraction system, built upon the principles developed by Vybin. The system's design and optimization is carried out using COMSOL Multiphysics and IBSIMU simulation tools, ensuring precise modeling of electric field fields and ion trajectories.

MOP10 **Light ions from the GTS-LHC ion source for future physics at CERN**

Detlef Kuchler, *Giulia Bellodi, Bichu Bhaskar, Richard Scrivens, Maciej Slupecki (CERN)*

Starting from 2028, physics programmes using ions at CERN have requested lighter ions than the lead usually produced. The Working Group on Future Ions in the CERN Accelerator Complex has been mandated to assess the feasibility of the production and operation of these new ion species. The ion beam production from two of the chosen elements, krypton and magnesium, was studied in the GTS-LHC ion source, and the preliminary results of beam intensity, stability and emittance will be presented, as well as proposed modifications to improve performance.

MOP11 **Continuous data-driven control of the GTS-LHC ion source at CERN**

Detlef Kuchler, Verena Kain *(CERN) Michael Schenk (EPFL) Simon Hirlaender (University of Salzburg)*

Recent advances with the CERN infrastructure for machine learning allows to deploy state-of-the-art data-driven control algorithms for stabilising and optimising particle accelerator systems. This contribution summarises the results of the first tests with different continuous control algorithms to optimise the intensity out of the CERN LINAC3 source. The task is particularly challenging due to the different latencies for control parameters that range from instantaneous response, to full response after only $\approx$30 minutes minutes. The next steps and a vision towards full deployment and autonomous source control will also be discussed.

MOP12 **Role of ECRISs to reveal astrochemical processes**

Richárd Rácz, *Sandor Biri, Péter Herczku, Zoltan Juhasz, Sándor Kovács, Rahul Kumar Kushwaha, Gergő Lakatos, Duncan Mifsud, Zoltan Perduk, Béla Sulik (Atomki) Thomas Field, Robert McCullough (Queen's University Belfast) Sergio Ioppolo (Aarhus University) Nigel Mason (CAPS)*

Electron Cyclotron Resonance (ECR) Ion Sources are widely used as the first stage of high energy (MeV – GeV) accelerators providing ion beams for versatile research fields including nuclear and particle physics. However, in the Atomki the 2nd generation 14 GHz ECR ion source operates as a standalone device opening the possibility to develop research areas requiring low energy ion beams in the range of 0.5–100 keV. One of this research fields is called astrochemistry. Astrochemistry has been the recipient of continuously increasing interest in the last few decades. The relevance of interstellar molecules to the emergence of life is strong motivation for better comprehending the astrochemical mechanisms leading to their formation and destruction. For this purpose, a new beamline and a special experimental chamber AQUILA (Atomki-Queen's University Ice Laboratory for Astrochemistry) were installed and commissioned recently to the Atomki ECRIS. AQUILA has been purposefully designed to study the chemical evolution of ices analogous to those that may be found in the dense interstellar medium or the outer Solar System as a result of their exposure to low energy ion beams. In this contribution the carefully designed ion transport system, the way of the well-controlled irradiation methods and also the main features of the AQUILA analytic system will be presented.

MOP13 **GANIL cyclotron and ion source for industrial application**

***Romain Frigot**, Mickael Dubois, Bertrand Jacquot (GANIL)*

The GANIL (Grand Accélérateur National d'Ions Lourds) in Caen produces up to 20 % of the beam times dedicated to industrial applications, such as the irradiation of electronic components.

The SAGA (Space Application at GAnil) project aims to increase beam times for these applications in the future in order to meet demand from French and European industries.

In this context, one of the challenges is to be able to switch rapidly from one beam to another in order to optimize the beam time available to industry. To meet these requirements, CIME's cyclotron could be an interesting device: it is capable of accelerating beams up to 20 MeV/A for light elements, and it can be used as a mass separator to select the desired beam. In order to supply stable ion beams to the CIME cyclotron, the charge breeder installed on the SPIRAL1 facility has been tested and adapted to provide a stable cocktail-type beam with a very close A/Q. Details of the project and initial results will be described.

MOP14 **ECR ions sources at CRC in UCLouvain, Belgium**

***François-Philippe Hocquet**, Nancy Postiau, Laurent Standaert (UCLouvain)*

The Cyclotron laboratory (CRC) was created in 1972 with the installation of the cyclotron "CYCLONE" (Kb = 110) in Louvain-la-Neuve, Belgium. Until late 90's, this cyclotron was dedicated to research in nuclear physics (ISOL RIBs, used for nuclear astrophysics measurements), nuclear chemistry and medicine (neutron and proton therapy). The CRC now mainly delivers ions beams for industrial applications as radiation hardness tests of electronic devices for space applications or micro-porous membrane production.

Our center has extensive experience (historically) with homemade ECR sources designed and built. Two ECR ions sources are used for our daily routine operations. The oldest, SCAMPI (Source Compacte Améliorée pour le Meilleur et pour le Pire, 6 GHz, 2 coils and permanent magnet, first beam in 1996), was used to produce heavy ions beams until the new ECR source came into operation and is mainly used nowadays to produce $^{40}Ar^{11+}$ and $^{40}Ar^{12+}$ beams. The second, BLUE WHALE (17,3 GHz, 3 coils and permanent magnet, first beam in 2016), is nowadays to produce heavy ions cocktail, including $^{124}Xe^{35+}$.

This poster presentation will present a status report on the variate applications, the performance of our ECR ion sources and our ongoing developments.

16 Sep – Mon

MOP15 **Study of noble gas memory effect of ECR3 at ATLAS**

***Robert Scott**, Jake McLain, Richard Vondrasek (ANL) Michael Paul (The Hebrew University of Jerusalem)*

Over the past three decades a portion of the accelerated beam time at the Argonne Tandem Linac Accelerator System (ATLAS) has been reserved for ultra-sensitive detection of argon radioisotopes. A unique noble-gas accelerator mass spectrometry (NOGAMS) technique at ATLAS combines electron cyclotron resonance ion source (ECRIS) positive ion production, acceleration up to 6 MeV/u and detection methods for separating isobars and other m/q contaminants. The ECR3 ion source was chosen for such experiments due to the limited scope of material introduced into the plasma chamber, inferring a lower background production compared to ECR2. A recent ^{39,42}Ar NOGAMS experiment has highlighted a need to understand the beam production of material that is no longer being actively introduced into the ECRIS, known as memory effect. A quantitative study of source memory was performed to determine the decay characteristics of argon in the ECR3 ion source. Results of this study as well as details of setup and operation of ECR3 for NOGAMS experiments are presented.

17-Sep-24 09:00 – 10:30	Welcome Hotel Darmstadt — Main Hall

TUA — Tuesday Oral Session MC4

Chair: Laurent Maunoury

TUA1 09:00 30

Design of a new iron plug for the TRIUMF ECRIS charge state booster

Joseph Adegun, *Friedhelm Ames, Oliver Kester (TRIUMF)*

This paper presents an innovative solution to address the issue of asymmetric dipole fields in the injection region of the TRIUMF electron cyclotron resonance ion source charge state booster. The asymmetric fields arise from a wide gap in the booster's injection soft iron plug, which allows the connection of the RF waveguide to the plasma chamber. Simulations have revealed that singly charged ions, injected for charge breeding, experience deflection and get lost due to the asymmetric magnetic fields instead of being effectively captured by the plasma, thereby diminishing the efficiency of the charge state booster. To rectify this problem, a novel iron plug with an enlarged inner diameter, which allows the RF waveguide to connect to the plasma chamber with no gap was designed. Furthermore, this new design necessitates alterations to the injection electrodes and plasma chamber of the booster. Additionally, the waveguide and gas-inlet windows were repositioned to ensure better RF coupling into the plasma cavity. By eliminating the gap and implementing these design changes, it is anticipated that the TRIUMF charge state booster will operate at the same overall efficiency as other PHOENIX boosters.

TUA2 09:30 30

ECR2 performance upgrades at ATLAS

Jake McLain, *Richard Vondrasek, Robert Scott (ANL)*

The user requests for higher beam energies and intensities have driven the decision to upgrade the ECR2 ion source at the Argonne Tandem Linac Accelerator System. Multiple upgrades are in progress with the expected outcome of dramatically increased ECR2 beam intensities and charge state capabilities. The magnetic upgrades include integrating an improved hexapole permanent magnet array that provides the ion source radial fields, reworking the magnetic materials surrounding the plasma chamber, and installing a new cooling system for the electromagnetic solenoids that govern the ion source axial fields. The new hexapole and higher solenoid magnet operating currents will increase the ion source magnetic fields and support the use of 18 GHz RF heating, further increasing the ECR2 beam capabilities. Following these improvements and subsequent source performance, simulations of beam transport devices on the ion source platform will need to be revisited for transmission of high intensity beams. Details of these upgrade projects and simulations of the ion optics are presented.

TUA3 10:00 30

The electrostatic deceleration of ions injected into an ECRIS CB plasma

***Julien Angot**, Thomas Thuillier (LPSC) Pierre Chauveau (GANIL) Alessio Galatà (INFN/LNL) Olli Tarvainen (STFC/RAL/ISIS)*

The capture of the 1+ beam is a key parameter in the charge breeding process with an ECRIS-Charge Breeder as it greatly influences the 1+N+ conversion efficiency. The shape of the efficiency vs incident ion energy «Delta V» curve originally led to the theory of slowing down of the injected ions essentially by cumulative small-angle scatterings in collisions with the buffer gas ions. Recent experiments carried out with the PHOENIX charge breeder at LPSC tends to show that the electrostatic deceleration plays a greater role than historically considered. For this study, we varied the CB plasma potential by acting on the microwave power parameter and by measuring the optimum injection energy for sodium, rubidium and cesium ions. Both i) the correlation between the plasma potential and optimum injection energy parameters and ii) the independence of the optimum energy value as a function of the incident ion mass support the new model based on a slowing down essentially electrostatic.

17-Sep-24 11:00 – 12:30 Welcome Hotel Darmstadt — Main Hall

TUB — Tuesday Oral Session MC8

Chair: Hongwei Zhao

TUB1 11:00 30

Progress in 3D self-consistent full wave-PIC modelling of space resolved ECR plasma properties

Angelo Pidatella, *Alessio Galatà, David Mascali, Giorgio Mauro, Bharat Mishra, Eugenia Naselli, Giuseppe Torrisi (INFN/LNS)*

We present updates of a simulation suite to model in-plasma ion-electron dynamics, including self-consistent electromagnetic (EM) wave propagation and ion population kinetics to study atomic processes in ECR plasmas. The EM absorption is modelled by a heuristic collisional term in the cold dielectric tensor. However, we are stepping beyond the cold approximation, modelling the hot tensor with non-collisional RF wave damping. The tool calculates steady-state particle distributions via a full wave-PIC code and solves for collisional-radiative process giving atomic population and charge state distribution. The scheme is general and applicable to many physics' cases of interest for the ECRIS community, including the build-up of the charge-state-distribution and the plasma emitted X-ray and optical radiation. We present its last updates and future perspectives, using as a case-study the PANDORA scenario. We report about studying in-plasma dynamics of injected metallic species and radioisotopes ionisation efficiency for different injection conditions and plasma parameters. The code is capable of reconstructing space-resolved plasma emissivity, to be directly compared to plasma emission measurements, and modelling plasma-induced modification of radioactivity.

TUB2 11:30 30

Simulation of the Bremsstrahlung emission induced by electrons impinging the plasma chamber walls of the ASTERICS ECRIS

Thomas Thuillier, *Andrea Cernuschi, Benjamin Cheymol, Christophe Peaucelle, Francis Vezzu (LPSC) Damien Simon (CEA-IRFU)*

A new electron cyclotron resonance ion source (ECRIS) named ASTERICS is under development for the NEWGAIN project, aiming at building a new injector for the SPIRAL2 accelerator at GANIL. A Monte Carlo code dedicated to the electron dynamics in ECRIS is used to investigate the local energy, position and velocity distribution of electrons impinging on the plasma chamber wall of ASTERICS. These quantities are presented for both the injection and extraction planes and the radial chamber wall. Results show that the electron energy distribution function is different on each of these three surfaces and that the electron velocity direction to the walls is deeply anisotropic. This data is next used as an input in a Fluka 3-dimensional model including the ASTERICS ECRIS mechanics, a simplified low energy beam line and the experimental cave in which the ion source will be installed. The x-ray flux characteristics around the source are presented. The shielding thickness and its location are studied to grant the safe passage of personnel around the ECRIS location in the accelerator building.

TUB3
12:00 30

Advances in PIC simulation of 2.45 GHz ECR ion sources

Lorenzo Neri, *Giuseppe Castro, Luigi Celona, Michele Comunian, Santo Gammino, Francesco Grespan, Ornella Leonardi, Andrea Miraglia (INFN/LNS) Giuseppe Bilotta (INGV-OE) Sebastiano Boscarino, Armando Coco, Giovanni Russo (Università degli Studi di Catania)*

INFN-LNS effort in PIC development for ECR Ion Sources is growing, and the collaboration is enlarging. Simulation capability is essential to reveal phenomena that diagnostics cannot catch. The simulation incorporates 3D charged particle motion, 3D electromagnetic simulation with tensorial permittivity, 2D axial symmetric Poisson solver, density evolution of neutral and excited particles, interaction with conductive and insulating walls, and electrostatic beam extraction. Recent upgrades include an adaptive time step and Poisson solver optimisation, allowing simulation of a hundred microseconds, with a time step of 2×10^{-12} seconds, in one month of computation. The chemical model was extended to 32 reactions and now includes the first excited atomic level of H and the first excited vibrational level of H_2. The secondary electron emission and the charge accumulation on the dielectric surface of Boron Nitride disks were implemented, and their role in the plasma formation was disclosed. The actual validation phase, where simulation results are compared to experimental data, will be reported. The commissioning of the PS-ESS source shows a region where the source does not produce a beam, even if powered by 600 W of RF power. This behaviour was fully disclosed by simulation and will be presented. The role of the different resonances acting on the standard high current configuration (MDIS) and super stable configuration (HSMDIS) will also be discussed.

17-Sep-24 14:00 – 15:30 Welcome Hotel Darmstadt — Main Hall

TUC — Tuesday Oral Session MC3

Chair: Guillaume Machicoane

TUC1 14:00 30

Simulation of Bremsstrahlung emission in ECRIS and its dependence on the magnetic confinement

Andrea Cernuschi, *Thomas Thuillier (LPSC)*

A Monte Carlo (MC) code dedicated to the electron dynamics in ECRIS was recently completed with a new functionality, allowing to simulate Bremsstrahlung photon emission from the volume interaction of electrons with charged particles inside the plasma. The simulation qualitatively reproduces the experimental anisotropy of the photon spectral temperature previously reported. The effects of variations in the magnetic field minimum Bmin and in the extraction peak on both the electron energy distribution function and the Bremsstrahlung emission are also investigated and reported. The simulation results confirm that only changes in Bmin influences the hot energy tail of the EEDF. The MC high electron statistics allows studying with unprecedent details the location and mechanism responsible for the hot electrons generation in ECRIS, highlighting the crucial role of B_{min} in this process.

TUC2 14:30 30

Status and perspectives of the PANDORA experiment: investigating β-decays in magnetized plasmas

David Mascali, *Domenico Santonocito (INFN/LNS)*

This contribution deals with the upcoming PANDORA (Plasmas for Astrophysics, Nuclear Decay Observations and Radiation for Archaeometry) facility, at INFN-LNS, Catania. PANDORA aims at measuring β-radioactivity rates and chemical element opacity in plasmas produced in an electron cyclotron resonance ion trap (ECRIT). The beta-decay rates are expected to vary of several orders of magnitude in a hot plasma, due to the interplay between the nuclear and atomic processes by the so-called bound-state-beta-decay mechanism (BSBD). Variations of decay rates have huge impact in astrophysical scenarios and cosmic nucleosynthesis processes, impacting on the chemical abundances in the Galaxy and in the early Universe. The PANDORA experimental setup will consist of:

1) a superconducting magnetic trap of 700 mm in length, 280 mm in diameter, operating up to 21 GHz, in triple-frequency heating mode;
2) an array of 14 of high efficiency High Purity Germanium detectors used to measure the gamma-rays emitted as by-products of beta-decays;
3) a unique multi-diagnostics system to characterize the plasma, including mm-wave super-heterodyne interfero-polarimeter, Thomson scattering, two high-resolution optical spectrometers, two CCD pin-hole camera systems for X-ray spectroscopy, imaging and tomography, SDD and Si-pin detectors for volumetric spectroscopy, and a mass-spectrometer.

The talk will give an overview about the status of the facility construction.

TUC3
15:00 30

Microwave transmission measurements at the VENUS ECR ion source

Janilee Benitez, *Sage Holter, Damon Todd (LBNL)*

The VENUS electron cyclotron resonance (ECR) ion source uses injected 18 and 28 GHz microwave power to resonantly energize electrons for plasma ionization. Waveguide antennas detecting 18 and 28 GHz microwaves located after the extraction electrode exit aperture of the source are used to measure the transmitted microwave power under different source and plasma conditions. In addition, an antenna is placed in the 28 GHz waveguide to measure 18 GHz microwaves that make it back out, during 18 GHz only operation. The relationship between the transmitted and reflected power is investigated. Measuring the transmitted power can aid in understanding how to efficiently couple the microwaves to the plasma so as to achieve the maximum source output. The transmitted power, which is inversely related to the absorbed power, is dependent on the neutral gas pressure, and the minimum magnetic field B_{min}. The production of $^{16}O^{6+}$ is also compared with the transmitted power.

17 Sep – Tue

17-Sep-24 16:00 – 17:00	Welcome Hotel Darmstadt — Main Hall

TUD — Tuesday Oral Session MC3

Chair: R. Rácz

TUD1
16:00 30

Time-resolved measurement of ion beam energy spread variation due to kinetic plasma instabilities in CW and pulsed operation of an ECRIS

***Ville Toivanen**, Hannu Koivisto (University of Jyväskylä) Juuso Huovila (University of Eastern Finland) Olli Tarvainen (STFC/RAL/ISIS)*

The energy spread of ion beams extracted from Electron Cyclotron Resonance (ECR) ion sources is influenced by plasma conditions such as the plasma potential, and effects taking place in the beam formation region. Kinetic plasma instabilities have a significant impact on the plasma properties, and consequently on the ion beam energy spread. We present experimental results of time-resolved energy spread behaviour when kinetic plasma instabilities are present in CW and pulsed operation of the JYFL 14 GHz ECR ion source. It is shown that the instability-induced energy spread variation corresponds to a momentary plasma potential increase up to several kV from the steady-state value of 10–30 V. The method for measuring the time-resolved energy spread variation is presented, and the consequences of the energy spread and the underlying plasma potential variation for ECRIS operation are discussed.

TUD2
16:30 30

A novel test-facility for ECRIS plasma diagnostics: optical spectroscopy, X-ray imaging and spectroscopy, mm-wave polarimetry

***Eugenia Naselli**, Giorgio Finocchiaro, David Mascali, Giorgio Mauro, Bharat Mishra, Bianca Peri, Angelo Pidatella, Giuseppe Torrisi (INFN/LNS) Richárd Rácz, Sandor Biri (Atomki)*

In the frame of the PANDORA project and the SAMOTHRACE ecosystem (Italian PNRR in the EU Next Gen Program contest), two new plasma diagnostics testbenches – PYN-HO and VESPRI2.0 setups – have been developed at INFN-LNS, with the aim to design and improve detectors and techniques beyond the state of art. The PYN-HO prototype is conceived to operate in four configurations: two of them to enhance high resolution X-ray imaging and space-resolved spectroscopy, also including X-ray tomography using multi pin-hole CCD systems, involving algorithms for Single Photon-Counted and High-Dynamic-Range analysis, with related calibrations via SDD; the other two are dedicated to high energy resolution diffractometric spectroscopic measurement in the X-ray and optical domains, based on micrometric gratings. The VESPRI2.0 mm-wave polarimeter is based on an innovative superheterodyne approach to measure plasma-induced Faraday rotation from Lissajous figure detection and estimate the plasma line-integrated density. *Prototypes can be installed in ECRIS for several plasma physics studies*, such as investigations of plasma structure, confinement dynamics, instabilities and turbulence, in-plasma and plasma vessel elemental composition, local thermodynamic parameters, etc. which are directly related to ion beam performances in ECRIS. The design and features of the prototypes and the first characterizations performed with Ar plasma in the INFN-LNS Flexible Plasma Trap will be presented.

TUP — Tuesday Poster Session

TUP01 **Operation with the LAPECR3 ion sources for cancer therapy accelerators**

Jiaqing Li, *Yun Cao, Wang Lu, Jindou Ma, Cheng Qian, Liangting Sun, Hui Wang, Xuezhen Zhang (IMP/CAS)*

An all-permanent magnet electron cyclotron resonance ion source-LAPECR3 (Lanzhou All Permanent magnet Electron Cyclotron Resonance ion source No.3) had been developed as the C^{5+} ion beam injector of Heavy Ion Medical Machine (HIMM) accelerator facility since 2009 in China. The first HIMM demo facility was built in Wuwei city in 2015, which had been officially licensed to treat patients in early 2020. The facility has been proven to be very effective, and more than 1000 patients have been treated so far. In order to prevent ion source failure, each facility employs two identical LAPECR3 ion sources to supply C^{5+} beam. At present, there are eight HIMM facilities under construction or in operation, and more than 16 LAPECR3 ion sources have been built. In order to improve the performance of the ion source for long term operation, some techniques were employed to optimize source performance and to avoid the damage of key equipment. This paper will introduce the operation status of LAPECR ion sources at these HIMM facilities and present the latest results of carbon beam production.

TUP02 **An electrostatic ion beam transport system for intense proton source**

Qi Wu, *Yuguo Liu, Liangting Sun, Hongwei Zhao (IMP/CAS)*

The Ion Source Group has undertaken a R&D project of a compact low energy injector. The project is the development of an intense proton source and low energy beam (LEBT) for a transportable neutron source. The specific characteristics of the injector are low power consumption, compact and low beam emittance. An electrostatic low energy beam transport with a double Einzel-Lens setup is used to deliver 30 keV H^+ beam to the entrance of a 2.5 MeV RFQ. A 2.45 GHz ECR ion source was adopted to provide 15 emA H^+, H^{2+} and H^{3+} beams with a duty factor of 3 %. The fabrication, assembly and beam commissioning have been completed at IMP. The injector composed the 2.45 GHz ECR ion source and its LEBT was very compact, with a length of 900 mm. The beam current at the LEBT exit was about 16 mA with a pulse length of 300 µs and a repetition frequency of 50 Hz. In this paper, the studies of beam intensities, beam transmission efficiency in LEBT, beam emittance and mismatch factor are presented and discussed.

17 Sep – Tue

TUP03 **Analysis of beam characteristic variations in the 14.5 GHz ECR ion source at RAON**

***Jeong Il Heo**, In-Seok Hong, Hyung Jin Kim (IBS)*

RAON (Rare isotope Accelerator complex for ON-line experiments) is a heavy ion accelerator under construction in Daejeon, South Korea. RAON plans to operate a 28 GHz Electron Cyclotron Resonance Ion Source (ECRIS) with a fully superconducting magnet and is currently operating a 14.5 GHz ECR ion source with a fully permanent magnet. The 14.5 GHz ECRIS was manufactured by PANTECHNIK and installed in our beamline in September 2020. The initial beam conditioning of RAON was conducted using the 14.5 GHz ECR ion source with $^{40}Ar^{9+}$ and $^{40}Ar^{8+}$ beams. Additionally, beam tests were performed with protons, $^{4}He^{2+}$, and oxygen. During these experiments, an unusual phenomenon was observed: the characteristics of the beam changed despite no variations in the parameters. This was consistently noted during some of the beam tests. We hypothesized several potential causes for this phenomenon and analyzed them through experiments. In this paper, we discuss the results of these analyses.

TUP04 **Tests of a low-energy pepperpot based on a micro-channel plate for high current protons sources 4D-emittance characterization**

***Anna Thézé**, Guillaume Ferrand (CEA-IRFU) Augustin Dubois, Olivier Tuske (CEA)*

In the scope of high current protons sources characterization, the CEA is working on a 4D-emittancemeter based on the pepperpot technology. After some unsuccessful developments with phosphorous scintillators, we decided to test micro-channel plates (MCP) for measurements of proton beams at very low energy (typically between 50 and 100 keV). MCP are supposed to resist to proton beams at very low energy better than scintillators. This work presents some results for MCPs with an ALISES source on the BETSI test bench.

TUP05 **RF and multipactor simulations in the plasma chamber of the SILHI proton source**

***Guillaume Ferrand, Mathias Barant** (CEA-IRFU) Augustin Dubois, Juliette Plouin, Olivier Tuske (CEA)*

In the scope of high current protons sources simulations, we tried to simulate the plasma chamber of the SILHI proton source with HFSS. This work focuses on the RF and multipactor simulation close to the boron nitride window.

TUP06 **Wien Filter upgrade and measurement for BETSI test bench**

***Augustin Dubois, Olivier Tuske**, Yannick Gauthier, Yannick Sauce (CEA) Olivier Delferriere (CEA-IRFU)*

During first operation of SILHI in 1995 at CEA Saclay, a velocity filter diagnostic (Wien Filter) was installed on the LEBT, analyzing the 100 mA of protons at 95 keV. The device was used many years providing beam proportion measurements on the beam axis. Unfortunately, it was damaged while handling and was no longer working as intended. This paper describes the maintenance and upgrade of the diagnostic as well as the first beam proportion figures with ALISES 2 and ALISES 3 ion sources.

TUP07 **Modification of the flexible plasma trap for high-intensity metal ion beams production**

***Carmelo Sebastiano Gallo**, Alessio Galatà, Salvatore Marletta, David Mascali, Giorgio Mauro, Angelo Pidatella, Santi Passarello, Antonio Domenico Russo, Giuseppe Torrisi (INFN/LNL) Giada Rachele Mascali (Sapienza University of Rome)*

NQSTI (National Quantum Science and Technology Institute) is the enlarged partnership on QST established under the National Recovery and Resilience Plan (NRRP) funded by the European Union – NextGenerationEU. In this framework, there is a growing interest in the availability of mA beams of singly charged (1+) metallic ions to realise quantum devices. To satisfy this request, the joint INFN Laboratories LNS and LNL proposed to modify the Flexible Plasma Trap (FPT), installed at LNS, thus transforming it into a simple mirror Electron Cyclotron Resonance Ion Source (ECRIS). This contribution describes the various technical solutions that will be adopted, foreseeing novel radial RF and gas/metal injection systems, focusing particularly on the design and simulations of a flexible extraction system capable of handling different beam intensities and ion species. Specifically, the project targets the production of high-intensity beams of singly charged ions such as Fe^+, and Ba^+, highlighting the versatility and innovation of the proposed modifications.

TUP08 **Planned optimization of the ion sources on the HIT test bench**

***Tim Winkelmann**, Rainer Cee, Thomas Haberer, Bernd Naas, Andreas Peters (HIT)*

The Heidelberg Ion Beam Therapy Center (HIT) is a hospital-based treatment facility in Germany. Since the first treatments in 2009, more than 8.500 patients have been irradiated with protons or carbon ions and since July 2021 with helium ions. At HIT, three Supernanogan ion sources supplied by Pantechnik are in operation around the clock for therapy up to 335 days a year.

A 4th Supernanogan ECR ion source is installed at the HIT test bench. The test bench is currently being prepared for a measurement campaign that will begin in October. The aim of the investigations is to obtain more beam current for the carbon ions used in therapy by feeding two microwave frequencies in parallel. We expect that this experiment will provide a better understanding of the ionization process in the ion source. In the first step we will feed 14.5 GHz and an extra frequency near the resonance frequency of 14.5 GHz ±0.5 GHz. In the second step we will feed in 14.5 GHz and 18 GHz.

To characterize and evaluate the beam quality in this setup, we will use the pepperpot a 4D emittance measuring device. In addition, it is possible to measure the beam current and the beam profile at the test bench.

This article provides an overview of the planned developments on the test bench.

TUP09 **Characterization of an proton ECR ion source for low beam current**

Pello Usabiaga, *Iñigo Arredondo, Joaquin Portilla, Jon Vivas (University of the Basque Country) Iratxe Ariz, Jose Mari Seara Eizaguirre (Fundación TEKNIKER) Jorge Feuchtwanger (Ikerbasque) Victor Etxebarria (UPV-EHU)*

In this paper we analyze the behavior of a low beam current proton ECR ion source for linac. During the operation of the source, as a function of the operating parameters we have observed a complex behavior. The state of the plasma is highly dependent on the input parameters, and in some cases even bi-stable conditions can be achieved showing abrupt changes in the state. To try to understand this behavior we carried out a series of experiments varying the input parameters both sequentially and randomly to avoid following the same path every time. Thanks to these experiments we have been able to observe the change in the luminosity of the plasma, which is an indirect measure of the degree of ionization in the plasma, along with the changes in reflected and transmitted RF power delivered to the source. We also characterized the relation between the outside temperature of the ion source chamber walls and the plasma. In addition to this we have analyzed the resulting extracted ion beam using a pepperpot and a faraday cup. We have observed that our beam doesn't have one dominant species and has three species that are found in comparable quantities.

TUP10 **Optical diagnostic studies of the electron cyclotron resonance plasma produced in the GTS-LHC ion source**

Bichu Bhaskar, *Detlef Kuchler (CERN) Toke Koevener (—)*

The GTS-LHC electron cyclotron resonance (ECR) ion source is an integral part of the chain of accelerators at CERN. It produces the heavy ion beams which are accelerated using a series of accelerators from LINAC up to the LHC. The ion beams are extracted from an ECR plasma generated at the GTS-LHC ion source, however, there has not yet been a non-invasive diagnostic device to study the plasma. This research focuses on the implementation of an optical diagnostics and studies the optical emission spectra (OES) as a monitor of the performance of the ion source. Furthermore, we explore the correlation between spectral properties and changing source parameters, offering insights into the behaviour of the ion source, which in turn helps in fine-tuning of the source. Specifically, the study concentrates on long-term OES analysis spanning several weeks, focusing on the production of magnesium and lead ions using the GTS-LHC ion source.

TUP11 **Efficient injection of high-intensity light ions from an ECR ion source into an RFQ accelerator**

***Chuan Zhang**, Eduard Boos (GSI)*

Aiming to produce a very intense heavy ion beam in a laser ion source and then to match it directly into an RFQ accelerator, the so-called direct plasma injection scheme (DPIS) has been investigated since 2000. This study investigates efficient injection of high-intensity light ions from an ECR ion source into an RFQ accelerator. Different scenarios e.g. without a low beam energy transport (LEBT) section or with a very compact LEBT (an electrostatic Einzel lens) for a better matching will be discussed, and the related simulation results will be presented.

TUP12 **A novel design of superconducting magnet for ECR ion source**

***Enmin Mei** (IMP/CAS)*

Since the powerful capability of producing high charge state ions for heavy ions and the long lifetime of the ECR ion source is deemed one of the most robust ion source types. So far, the 3rd generation ECR built with NbTi superconductor has a wonderful performance reference to the ECR used by LBNL and IMP-CAS for a long time. However, this type of ECR has not got a well spread and further development either in accelerator systems or in other areas. The reason is its inefficiency of electromagnetic design and the complexity of mechanical structure design and technical realization. Aim to conquer this embarrassing situation of the 3rd ECR magnet. This paper proposes a novel structure design that combines minimal layers of solenoids and Discrete-Cosine-Theta coils that are embedded in the machined grooves. Besides the high magnetic field generation efficiency, this structure can also reduce the accumulation of the coils' Lorentz forces. The details of the electromagnetic mechanical design of this new magnet structure will be described in this paper.

TUP13 **Transport of intense Bi and U beams into an RFQ**

***Gerard Oscar Rodrigues** (IUAC)*

A 48.5 MHz RFQ has been designed to transport and accelerate $^{238}U^{40+}$ (0.52 emA) and $^{208}Bi^{30+}$ (1.047 emA) beams extracted from a high performance ECR ion source. The RFQ design comprises of a pre-buncher built into the vanes to narrow the transmitted charge state distribution as much as possible. The design parameters as a function of cell length is optimised on $^{208}Bi^{30+}$. It is shown that the losses of various ions without using an inlet aperture are inevitable, but by proper coating of the vanes of the RFQ, sputtering can be minimised to a great extent. Titanium shows better results when compared with gold or copper and this has been verified using the modelling results from SRIM.The design details of matching the ECR and the RFQ and the predicted performance will be presented.

17 Sep – Tue

TUP14 **3D simulations of the CAPRICE ECRIS extraction system**

Michael Händler *(Goethe Universität Frankfurt) Alexander Andreev, Giuliano Franchetti, Michael Galonska, Ralph Hollinger, Ralf Lang, Fabio Maimone, Jan Maeder (GSI)*

The simulation of the ion extraction from the Electron Cyclotron Resonance Ion Sources (ECRISs) is necessary for the optimization and development of the performance of ion sources. Due to the magnetic field configuration of the ECRISs the calculations need to be performed in 3D. Therefore simulation programs based i.e. on C^{++} libraries like IBSimu were developed. In this work a physical model was implemented in IBSimu generating detailed 3D simulations of ion extraction from a CAPRICE-type ECRIS. Simulations of multi-species Argon ion beam including Helium contribution as support gas extracted from CAPRICE are carried out. The study includes the effect of different space charge compensation degrees. Furthermore, ion beams extracted with different plasma electrode apertures were analyzed in terms of ion beam current, beam profile, beam size, divergence angle, and beam quality. In addition the simulation results were compared to experimental findings, i.e. ion beam intensities and beam profiles measured with viewing screens.

TUP15 **Extrapolation of axis-symmetric magnetic fields in MDIS and ECRIS**

Giuseppe Castro*, Luigi Celona, Giacomo Costanzo, Grazia D'Agostino, Santo Gammino, Ornella Leonardi, Davide Siliato (INFN/LNS)*

Microwave discharge ion sources (MDIS) and electron cyclotron resonance ion sources (ECRIS) are widely used to feed particle accelerators. Their magnetic field consists in an axis-symmetric magnetic field that can be produced by permanent magnets or coils with the aim of assuring plasma heating by electron cyclotron resonance and confining the plasma axially. In ECRIS, a sextupole is added for radial plasma confinement. The 3D configuration of the magnetic field is needed to simulate beam extraction and plasma particles motion in the plasma chamber. Due to mechanical constraints, the measurement of the magnetic field in the entire chamber volume is often difficult or not possible. This work introduces a numerical method for magnetic field extrapolation in the whole ion source volume by experimental measurements of the magnetic field in the plasma chamber along the axis. The approach has been validated by comparing extrapolated values with experimental measurements.

WEA — Wednesday Oral Session MC6

Chair: Luigi Celona

WEA1 09:00 30

Characterization of D^+ species in the 2.45 GHz ECRIS for 14-MeV neutron production

Sudhirsinh Vala, *Mitul Abhangi, Rajesh Kumar, Ratnesh Kumar, HL Swami (Institute for Plasma Research)*

The Institute for Plasma Research has set up a 14-MeV neutron generator facility. The stability, quality, and repeatability of the D^+ ion beam are critical parameters for ensuring the reliable operation of the neutron generator. Hence, a 2.45 GHz ECR ion source has been installed to produce the deuterium beam. The primary D beam characteristics are assessed by varying extraction voltage, microwave power, gas flow, and solenoid current of the ECRIS. By optimizing these parameters, the maximum design beam current is achieved. The D ion beam contains various species, including D^+, D^{2+}, D^{3+}, and impurities. Accurate measurement of the D^+ content within the D ion beam is the key parameter for a neutron generator. Multiple experiments were conducted to determine the D^+ species and optimise the ECRIS parameters for maximum production of D^+ species. Two beam current measurement devices, the DCCT and the Faraday Cup, were installed in the beamline to measure the total deuterium beam current and D^+ beam current, respectively. Notably, the variation in the D^+ fraction primarily depends on the operating parameters of the ECRIS, such as extraction voltage, microwave power and gas flow. This paper presents the results of the D^+ ion current as a function of extraction voltage, microwave power, and gas flow rate. Understanding and characterizing the D^+ species are essential steps toward achieving stable and efficient neutron production in fusion applications.

WEA2 09:30 30

Compact 2.45 GHz PMECR ion sources developed for accelerator based radiation therapy facilities at Peking University

ShiXiang Peng, *Bujian Cui, Yicheng Dong, Zhiyu Guo, Kai Li, Tenghao Ma, Wenbin Wu (Peking University) Jia-er Chen (National Natural Science Foundation of China)*

Recently, Accelerator Based Radiation Therapy (ABRT) facilities for cancer treatment, that includes ion therapy and BNCT, have been bloomed up rapidly and is being established as a future modality to start a new era of in-hospital facilities around the world. A high current, small emittance, easy maintenance, long lifetime, high stability and reliability ion source is crucially important for those ABRT facilities. Research on this kind of characters ion source has been launched at Peking University (PKU) ion source group for more than 30 years and some exciting progresses, such as hundred mA $H^+/N^+/O^+$ etc. beam current, less than 0.2 π·mm·mrad emittance, a continue 300 hours non-sparking CW proton operation record have been achieved. Recently, we also involved in the ABRT campaign by in charging of ion sources. In this paper, we will summarize the several compact PKU 2.45 GHz permanent magnet ECR sources (PMECR) that were developed for proton therapy machines and BNCT facili-

ties. The individual structure of the sources as well as the LEBT along with the commissioning results will be presented then.

WEA3 10:00 30

A plasma based, charge state stripper for heavy ion accelerators

Gerard Rodrigues (IUAC)

The ionization of ions to a higher charge state is of central importance for the development of new Accelerator Facilities like FAIR, and the resulting cost savings. Currently, mainly gas and foil strippers are used for increasing the charge state even after using a high performance ECR ion source in a typical Accelerator chain. Even when the foil or/and gas stripper efficiency or lifetime has proved to be less than optimal, as these alternatives either require great effort or are practically not suitable for smooth operation in the long term. Free electrons in highly ionized plasmas can be effectively used for improving the charge state of heavy ions as the rates of radiative recombination of free electrons are much smaller than those of electron capture on bound electrons, which leads to a substantial increase of the effective charge in a plasma compared to a cold-gas target of the same element. Theta and Z pinch plasmas are possible options which have been explored and experimentally studied at IAP, Frankfurt, Germany. Typical electron line densities required to be achieved are in the range of 10^{16} to 10^{19} cm^{-3} and electron temperatures of the order of few tens of eV are found to be very favourable as per modelling with the FLYCHK code, but also extremely challenging. Such a plasma device, the challenges to be overcome, together with their design details will be presented.

WEB — Wednesday Oral Session MC6

Chair: Sudhirsinh Vala

WEB1 10:50 30

Mixed carbon and helium ion beams for simultaneous heavy ion radiotherapy and radiography: an ion source perspective

Michael Galonska, *Alexander Andreev, Christian Graeff, Ralph Hollinger, Jan Maeder, Fabio Maimone, Lennart Volz, Ralf Lang (GSI)*

Within the framework of research on simultaneous heavy ion radiotherapy and radiography, a mixed carbon/helium ion beam with a variable He percentage has been successfully established and investigated at GSI for the first time in order to study this new mode of image guidance for carbon ion beam therapy.

The mixed C/He ion beam was provided by the 14.5 GHz CAPRICE ECR ion source for the subsequent linac-synchrotron accelerator systems at GSI. Prior to that experiment, different ion combinations ($^{12}C^{3+}/^{4}He^{+}$ or $^{12}C^{4+}/^{3}He^{+}$) out of CH_4 or CO_2 have been investigated at the ECR test bench in terms of ion beam currents, stability, and C-to-He-fraction quantified by optical spectral lines and mass spectra. From an ion source perspective, it turned out that each of the different combinations comply with all the requirements of the experiments which successfully took place utilizing a $^{12}C^{3+}/^{4}He^{+}$-ion beam with an energy of 225 MeV/u. Finally, both ions were simultaneously accelerated and extracted and characterised in the biophysics cave.

This paper briefly outlines some of the measurements obtained at the test bench and during the beam time from an ion source perspective.

WEB2 11:20 30

Applying machine learning techniques to the operation of the superconducting ECR ion source VENUS

Damon Todd, *Janilee Benitez, Heather Crawford, Alex Kireeff, Yue Shi Lai, Marco Salathe, Victor Watson (LBNL)*

An operator of the superconducting ECR ion source VENUS tasked with optimizing the current of a specific ion species or finding a stable operating mode is faced with an operation space composed of ten-to-twenty knobs in which to determine the next move. Machine learning techniques are well-suited to multidimensional optimization spaces.Over the last three years we have been working to employ such techniques with the VENUS ion source. We will present how the introduction of computer control has allowed us to automate tasks such as source baking or to utilize optimization tools to maximize beam currents with no human intervention. Our more recent applications of Bayesian optimization and reinforcement learning to beam current maximization and the maintenance of long term source stability will also be presented. Finally, we will discuss control and diagnostic changes that we have employed to exploit the faster data collection and decision making abilities when VENUS is under computer control.

WEB3 11:50 30

Beam intensity prediction using ECR plasma images and machine learning

Yasuyuki Morita *(Osaka University), Ayumi Kasagi (Rikkyo University) Keita Kamakura (University of Tokyo) Naoya Oka (NICT) Takahiro Nishi (RIKEN)*

Long-term beam stability is one of the important issues in supplying multivalent heavy ion beams using an Electron Cyclotron Resonance Ion Source (ECRIS). When the beam intensity drops for long-term operation, the ECRIS parameters need to be tuned to restore the original beam intensity. Continuous measurement of the beam intensity using a Faraday cup (FC) is impractical while the beam is in use. We have had to rely on an unreliable method of monitoring the total drain current to estimate the beam intensity during beamtime. To resolve this issue, we propose a new method for predicting the beam intensity at FC using machine learning. Our approach incorporates plasma images, captured through a hole in the beam extraction electrode, and operating parameters as input data for the machine learning model. In short-term test datasets, our model has successfully produced rough predictions of the beam intensity. This presentation will detail the prediction model and its prediction results on the test data.

18-Sep-24 13:30 – 19:00	Conference Excursion
WEO — Excursion	

Conference Outing/Excursion

18-Sep-24 19:00 – 22:00	Social Conference Dinner
WES — Social Dinner	

Social Conference Dinner

19-Sep-24 10:10 – 11:40	Main Lecture Hall (GSI)

THA — Thursday Oral Session MC1 & MC2
Chair: Ralph Hollinger

THA1 10:10 30
High performance highly-charged ECR ion sources and matching with high-intensity heavy ion accelerator facility

Hongwei Zhao, *Liangting Sun (IMP/CAS)*

Five ECR ion sources operating at 18-45 GHz microwave frequency are being operated or under commissioning to deliver highly-charged ion beams for high-intensity heavy ion cyclotron and linac accelerators at IMP in order to meet different requirements from the accelerators and physics experiments. One of the key issues for the ECRIS and accelerator physicists is how to match the highly-charged ECR ion sources with the accelerators and maximize performance of the accelerators from the point of view of beam intensities, charge states and costs. This paper will discuss how a highly-charged ECR ion source could match with a high-intensity heavy ion accelerator performance cost effectively on the basis of our operation experiences with the five ECR ion sources and the accelerators. If a new high-intensity heavy ion cyclotron or linac would be designed and built, performance and cost can be compared in detail for the cyclotron with an ECR ion source delivering Xe^{20+} and Xe^{35+}, and for the linac with an ECR ion source delivering U^{35+} and U^{55+}. Finally, it has been demonstrated that development of a highly-charged ECR ion source producing intense beams is more performance-cost-effective for a high-intensity heavy ion accelerator.

THA2 10:40 30
Numerical design of an innovative superconducting magnetic trap for probing β-decay in ECR plasmas

Giorgio Mauro, *Alessio Galatà, Giorgio Finocchiaro, David Mascali, Bharat Mishra, Eugenia Naselli, Angelo Pidatella, Filippo Russo, Domenico Santonocito, Giuseppe Torrisi (INFN/LNL)*

The main aim of Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry (PANDORA) project is to build a flexible magnetic plasma trap where plasma reaches a density $n_e \sim 10^{11}–10^{13}\,\mathrm{cm}^{-3}$, and a temperature, in units of kT, $kT_e \sim\ 0.1 – 30$ keV in order to measure, for the first time, nuclear β-decay rates in stellar-like conditions. Here we present the numerical design of the PANDORA magnetic system, carried out by using the commercial simulators OPERA and CST Studio Suite. In particular, we discuss the design choices taken to:

1) obtain the required magnetic field levels at relevant axial and radial positions;
2) avoid the magnetic branches along the plasma chamber wall;
3) find the optimal position for the set of plasma diagnostics that will be employed.

The magnetic trap has been conceived to be as large as possible, both in radial and axial directions, in order to exploit the plasma confinement mechanism on a bigger plasmoid volume. The plasma chamber will have a length of 700 mm and a diameter of 280 mm. The magnetic trap tender procedure has been completed in June 2024 and the structure realization is expected to start in late 2024.

THA3 11:10 30

Waveguide DC breaks with optimized impedance matching networks

Michel Kireeff Covo, *Brien Ninemire, Damon Todd, Daniel Xie, Jaime Cruz Duran, Janilee Benitez, John Paul Garcia, Larry Phair, Michael Johnson, Patricius Bloemhard (LBNL)*

A custom 18 GHz waveguide DC break with a built-in impedance matching network, consisting of two inductive irises adjacent to a capacitive gap assembled around a quartz disk, was built for VENUS and simulated using the ANSYS High Frequency Structure Simulator, a finite element analysis tool. The DC break effectively doubled the RF power available for plasma production at the secondary frequency of 18 GHz while maintaining a DC isolation of 32 kV. Measurements of the forward and reflected power coefficients, performed with a network analyzer, showed excellent agreement with the simulations. Additionally, an extended study was conducted to tailor the frequencies of 28, 35, and 45 GHz using WR-34, WR-28, and WR-22 waveguides with built-in impedance matching networks, aiming to predict performance for our upcoming 4th generation low-power, multi-frequency operation of the MARS-D ion source.

19-Sep-24 11:55 – 13:00	Main Lecture Hall (GSI)
THC — Geller Prize & Closing Session	

THCS 11:55 65

Geller Prize & Closing Remarks

19-Sep-24 14:00 – 16:00	GSI
THV — GSI Visit	

Visit of GSI/FAIR construction site