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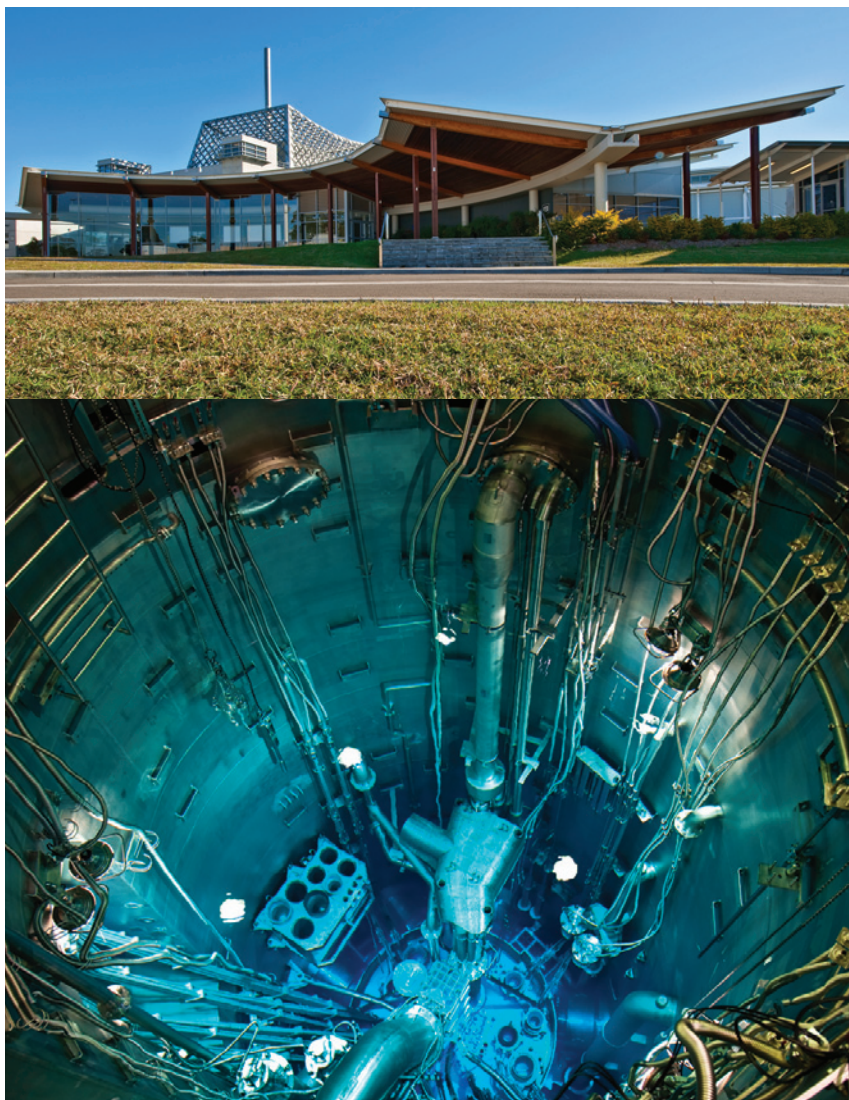
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**Ansto**



20th International Workshop on  
Electron Cyclotron Resonance Ion Sources  
(ECRIS-2012)

25th-28th September 2012  
Sydney, Australia



Top, the OPAL building at ANSTO and above inside the reactor.

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# Organisational partners



Australian Government

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Australian  
National  
University

# Welcome

On behalf of the Organising Committee, I am pleased to welcome you to the 20th International Workshop on Electron Cyclotron Resonance Ion Sources (ECRIS-2012), being held in Sydney, Australia, from 25th-28th September 2012.

Following the last workshop in Grenoble, the birthplace of ECR ion sources, it is perhaps fitting that the workshop comes to Sydney this year, on the very opposite side of the planet, to show that ECRIS science and technology has indeed literally spread all around the world.

The workshop will focus on the latest developments in performance, modelling and applications of ECR ion sources along with the associated physics and technologies.

The workshop is organised by the Australian Nuclear Science and Technology Organisation (ANSTO), with the support of the Australian Institute of Nuclear Science and Engineering, the Australian National University in Canberra and the Australian Collaboration for Accelerator Science.

I take this opportunity to thank our sponsors for their generous support:

Major sponsors / exhibitors: Pantechnik, Scitek and Swagelok.

Sponsors: John Morris Scientific, Agilent Technologies, Integrated Engineering Software, National Electrostatics Corporation and National Instruments.

Sydney is pre-eminently a harbour city. The principal venue for our workshop is the Australian National Maritime Museum, right by the water in Darling Harbour, in the heart of the city. The museum showcases Australia's maritime history. You will also have opportunities to absorb the ambience of the harbour city at the workshop dinner and the excursions.

I trust that you will enjoy the workshop and your time in Sydney.

Michael Hotchkis

Chair, ECRIS 2012

## Major Sponsors



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# ECRIS 2012 Organisation

## **Workshop Chair:**

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## **International Advisory Committee:**

- J Beijers, KVI, Netherlands
- S Bogomolov, JINR, Russia
- S Gammino, INFN-LNS, Italy
- D Kanjilal, IUAC, India
- H Koivisto, University Of Jyväskylä, Finland
- T Lamy, LPSC, France
- R Leroy, GANIL, France
- C Lyneis, LBNL, USA
- T Nakagawa, RIKEN, Japan
- R Vondrasek, ANL, USA
- P Spädtke, GSI, Germany
- T Thuillier, LPSC, France
- H Zhao, Institute Of Modern Physics, China

# Intro

## 2012 Richard Geller Prize

In recognition of outstanding contributions to the development of ECR (Electron Cyclotron Resonance) 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 ECRIS workshops.

This prize will be awarded for the third time during the 20th International Workshop on Electron Cyclotron Resonance Ion Sources in Sydney (2012).

Award: Award Certificate and 4,000 €.



### **Geller Prize Award Committee:**

Thomas Thuillier (Chair), Laboratoire de Physique Subatomique et de Cosmologie, Grenoble

Santo Gammino, Laboratori Nazionali del Sud, INFN, Catania

Michael Hotchkis, Australian Nuclear Science and Technology Organisation, Lucas Heights

Claude Lyneis, Lawrence Berkeley National Laboratory, Berkeley

Takahide Nakagawa, Nishina Center for Accelerator Based Science, RIKEN

Hongwei Zhao, Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou

### **Previous winners:**

2008: Liangting Sun, IMP, Lanzhou

2010: Olli Tarvainen, JYFL, Jyväskylä



## General Information

Maps and guides are provided in the workshop satchels.

### **Main venue – Australian National Maritime Museum**

Delegates are able to visit the museum collections at any time during normal opening hours, except for special exhibitions and the vessels, for which tickets must be purchased.

Lunches are not provided. There are many options in the immediate neighbourhood of the museum.

**Tasman Light and Deck:** registration desk; exhibitors area; morning and afternoon teas.

The Registration Desk will be open 6am to 8pm Monday; 8am to 5pm Tuesday; 8am to 5pm Wednesday; 8am to 1pm Thursday.

Registration desk phone number: 0438 437 381

**The Theatre:** all oral sessions except Friday.

**The Terrace Room:** poster sessions on Tuesday and Wednesday afternoons.

**Smoking policy:** smoking is not permitted indoors.

**Computers:** information on wifi access will be provided separately in the conference satchel. A computer desk is provided in the Tasman Light and Deck area.

**Oral sessions:** presentations should be in Powerpoint or PDF format. Please bring your presentation on a memory stick. If you are able to upload your presentation in advance (via JACoW), it will be accessible on the Theatre console computer directly. Please verify this or provide your presentation to our staff for installation on the computer at least one hour before your session is due to start. The Theatre computer is a PC with Microsoft Office 2010 installed.

**Poster sessions:** posters should be put up in the Terrace Room during the lunch break on Tuesday. All posters should be on display for both poster sessions. Poster presenters should attend their poster on the day allocated (Tuesday for posters numbered TUPPnn, Wednesday for WEPPnn). Posters must be removed at the end of the Wednesday session.

# Intro

**Security:** you must take care of your own valuables. The museum is open to the public during the workshop. You must wear your name badge to gain access to the museum.

## Friday sessions and ANSTO visit

Meet at the Australian National Maritime Museum at 8.30am sharp for departure by coach to ANSTO.

Sessions are in the morning, followed by lunch, which is provided.

The laboratory tour at ANSTO will commence at 2.15pm and finish by 4.30pm, and then the coach will take delegates back to the city.

For those not attending the tour, a coach will depart from ANSTO at 2.30pm.

Cameras, including those in mobile phones and similar devices, are not permitted on the laboratory tour.

## Social programme

### Welcome Reception

The Welcome Reception will be held at the Australian National Maritime Museum, on board HMAS Vampire, from 6 to 9pm on Monday 24th September.

### Workshop Dinner

The workshop dinner will be held on Wednesday 26th September from 7 to 11pm, at Waterfront Restaurant, Circular Quay West, The Rocks, Sydney. The workshop will use a private dining area, Settlers Hall, on the second floor of the restaurant. Access to Settlers Hall is at 5 Hickson Road, behind the main public restaurant area.

Transport to/from the restaurant is not provided and we ask participants to make their own way there. The location is shown on the map on page 10. It is about 2.5km from the main workshop venue in Darling Harbour.

To reach Waterfront Restaurant, we suggest the following options:

- take the ferry (Darling Harbour to Circular Quay), then walk 500m around Circular Quay West
- walk via city streets (cross Pyrmont Bridge, straight ahead up Market St, left on to George St, through The Rocks to Hickson Rd)
- catch a Water Taxi (to Campbell's Cove / Hickson Rd)
- city taxi

## Excursions

There are two excursion options on Thursday afternoon. These have been pre-booked at the time of registration.

**Harbour Cruise.** The departure point is King Street Wharf, Darling Harbour. To reach King Street Wharf from the Australian National Maritime Museum, cross Pyrmont Bridge, turn left and follow the waterfront past the Aquarium. Total distance about 800m. Please be there at 1.50pm for departure at 2.00pm. The cruise finishes at the same location, at 6pm.

We suggest you bring hat, sunglasses, sunscreen and windproof jacket.

**Harbourside Bushwalk.** Please meet at the Australian National Maritime Museum at 1.30pm for departure by coach to the starting point of the walk. The walk finishes at Manly and you will be provided with a ticket for the journey from Manly back to Sydney CBD by ferry. You will therefore finish at Circular Quay ferry terminal from which you will need to make your own way back to your accommodation.

Please bring water, hat, sunscreen and windproof jacket, and wear suitable walking shoes.



**Workshop Dinner venue:  
Waterfront Restaurant**

Sydney  
Opera  
House

**Circular  
Quay**

**Circular Quay**

**King St  
Wharf**

**Darling  
Harbour**

**Venue: Australian  
National Maritime  
Museum**

**Cockle  
Bay**

**Tumbalong Park**

100m

## Summary Program

	Monday 24th Sept	Tuesday 25th Sept	Wednesday 26th Sept	Thursday 27th Sept	Friday 28th Sept
<b>Session</b>		8:00 Registration			8:30 Depart ANMM
<b>Tea</b>					
<b>Session</b>		<b>TUXO</b> 8:40-10:20 Opening / Plasma Physics & Applications	<b>WEXO</b> 8:30-10:30 Ion Production & Modelling	<b>THXO</b> 8:50-10:20 Superconducting Sources	<b>FRXA</b> 9:20-10:50 New Developments and Status Reports
<b>Tea</b>					
<b>Session</b>		<b>TUYO</b> 11:00-12:30 Plasma Physics & Techniques	<b>WEYO</b> 11:00-12:30 Ion Beam Extraction & Optics	<b>THYO</b> 11:00-12:30 Charge Breeding and Radioactive Ion Beams	<b>FRYA</b> 11:10-12:50 Status Reports / Closing
<b>Lunch</b>					ANSTO lunch
<b>Session</b>		<b>TUZO</b> 14:00-15:50 Ion Beam Extraction & Optics	<b>WEZO</b> 14:00-15:50 New Developments and Next Generation Sources	13:30-18:00 Excursions	14:15-16:30 ANSTO Tour
<b>Tea</b>					
<b>Session</b>		<b>TUPP</b> 16:00-18:00 Posters	<b>WEPP</b> 16:00-18:00 Posters		
<b>Evening</b>	18:00-21:00 Welcome Reception		19:00-23:00 Workshop Dinner		

# Program

## ECRIS 2012 Program

Tuesday, 25 September 2012

Australian National Maritime Museum

08:40 - 08:52	Welcome	
<b>TUXO</b> 08:52 - 10:20	<b>Plasma Physics &amp; Applications</b> Chair: Richard Vondrasek	
08:52	<b>TUXO01</b> Coupling Microwave Power into ECR Ion Source Plasmas at Frequencies above 20 GHz	Claude M Lyneis – LBNL, USA
09:14	<b>TUXO02</b> An Experimental Study of ECRIS Plasma Stability and Oscillation of Beam Current	Olli Tarvainen – JYFL, Finland
09:36	<b>TUXO03</b> Two-frequency Heating Technique for Stable ECR Plasma	Atsushi Kitagawa – NIRS, Japan
09:58	<b>TUXO04</b> Ultra-High Sensitivity Determination of $^3\text{He}/^4\text{He}$ Abundances in Helium by Accelerator Mass Spectrometry for Neutron Lifetime Measurement	Michael Paul – Hebrew University, Israel
<b>TUYO</b> 11:00 - 12:30	<b>Plasma Physics &amp; Techniques</b> Chair: Vladimir Zorin	
11:00	<b>TUYO01</b> Experimental Study of Temperature and Density Evolution During Breakdown in a 2.45 GHz ECR Plasma	Osvaldo Daniel Cortázar – ESS Bilbao, Spain
11:22	<b>TUYO02</b> New Conception of the Control of Plasma Transversal Losses, Caused by MHD Instabilities, in Open Mirror Magnetic Traps: Experiments on SMIS 37 Setup	Alexander Sidorov – Institute of Applied Physics, Russian Academy of Sciences
11:44	<b>TUYO03</b> Secondary-electron-enhanced Plasma as an Alternative to Double/Variable-frequency Heating in ECRIS	Kurt Ernst Stiebing – Goethe Universität, Germany
12:06	<b>TUYO04</b> Neutral Gas Temperature Measurements of a Radio Frequency Micro-thruster	Amelia Greig – SP3, ANU, Australia

<b>TUZO</b> 14:00 - 15:50	<b>Ion Beam Extraction &amp; Optics</b> Chair: Peter Spaedtke	
14:00	<b>TUZO01</b> Beam Extraction Results with KAERI 14.5 GHz ECR Ion Source	Byung-Hoon Oh – KAERI, Republic of Korea
14:22	<b>TUZO02</b> The Surprising Effect of Limiters and why Multiple Beam-lets Emerge from one Pepper Pot Hole	Herman R. Kremers – KVI, The Netherlands
14:44	<b>TUZO03</b> New Extraction Design for the JYFL 14 GHz ECRIS	Ville Toivanen – JYFL, Finland
15:06	<b>TUZO04</b> Space Charge Compensation Measurements of Multicharged Ion Beams Extracted from an ECR Ion Source	Daniel Winklehner – LBNL, USA
<b>TUPP</b> 16:00 - 18:00	<b>Tuesday Poster Session</b> The Terrace Room	
16:00	<b>TUPP01</b> Quantitative Determination of $^{146}\text{Sm}/^{147}\text{Sm}$ Ratios by Accelerator Mass Spectrometry with an ECR Ion Source and Linear Acceleration for $^{146}\text{Sm}$ Half-Life Measurement	Michael Paul – The Hebrew University, Israel
	<b>TUPP02</b> Performance of a New Compact ECR Ion Source for Stable Isotope Mass Spectrometry	David Button – ANSTO, Australia
	<b>TUPP03</b> Integration of a Third Ion Source for Heavy Ion Radiotherapy at HIT	Tim Winkelmann – HIT Heidelberg, Germany
	<b>TUPP04</b> Design of New Compact ECR Ion Source for Production of Various Ions	Atsushi Kitagawa – NIRS, Japan
	<b>TUPP05</b> Charge-breeding at the Texas A&M University Cyclotron Institute	Donald Philip May – Texas A&M University Cyclotron Institute, USA
	<b>TUPP07</b> Upgrading of the CAESAR Ion Source at INFN-LNS	Giovanni Ciavola – INFN-LNS, Italy

## Tuesday, 25 September 2012 (con'd)

	<b>TUPP08</b> Design Report of the AISHA Ion Source for Hadron Therapy Facilities	Giovanni Ciavola – INFN-LNS, Italy
	<b>TUPP09</b> R&D Plan of the ECR Ion Sources for RISP	In-Seok Hong – IBS, Republic of Korea
	<b>TUPP10</b> Operational Experience with the GTS-LHC Ion Source and Future Developments of the CERN Ion Injector	Detlef Kuchler – CERN
	<b>TUPP11</b> The Status Report of Superconducting ECR Ion Source in KBSI	Byoung Seob Lee – KBSI, Republic of Korea
	<b>TUPP12</b> Design of Web-based Interface to RIKEN 28 GHz Super-conducting ECR Ion Source and the Future Plan	Yoshihide Higurashi – RIKEN Nishina Center, Japan
	<b>TUPP13</b> Development of Intense Proton Beam ECR Ion Source at IMP	Zimin Zhang – IMP, Lanzhou, China
	<b>TUPP14</b> Beam Experiments with the Grenoble Test Electron Cyclotron Resonance Ion Source at iThemba LABS	Rainer Thomae – iThemba LABS, South Africa
	<b>TUPP15</b> Test Results of Superconducting Magnet System for 28 GHz Electron Cyclotron Resonance Ion Source at KBSI	Seyong Choi – KBSI, Republic of Korea
	<b>TUPP16</b> Conceptual Design of a Superconducting Magnet ECR Ion Source for the Korean Rare Isotope Accelerator	Byung-Hoon Oh – KAERI, Republic of Korea
	<b>TUPP17</b> Installation and Operation of a 28 GHz Gyrotron for the RIKEN Superconducting ECR Ion Source	Yoshihide Higurashi – RIKEN, Japan
	<b>TUPP18</b> DECRIS-5 Ion Source for DC-110 Cyclotron Complex	Vladimir Mironov – KVI, The Netherlands



## Wednesday, 26 September 2012 Australian National Maritime Museum

<b>WEXO</b> 08:30 - 10:30	<b>Ion Production &amp; Modelling</b> Chair: Nikolai Lobanov	
08:30	<b>WEXO01</b> Special presentation by invitation of the organising committee: Ion Beam Formation in Expanding Plasmas and its Application to Plasma Thrusters	Christine Charles – SP3, ANU, Australia
09:02	<b>WEXO02</b> Recent Developments and Electron Density Simulations at the ATOMKI 14 GHz ECRIS	Sandor Biri – ATOMKI, Hungary
09:24	<b>WEXO03</b> Numerical Modeling of Ion Production in ECRIS by using the Particle-in-Cell Method	Vladimir Mironov – KVI, The Netherlands
09:46	<b>WEXO04</b> Proton Beams Formation from Dense Plasma of ECR Discharge sustained by 37.5 GHz Gyrotron Radiation	Vadim Skalyga – Institute of Applied Physics, Russian Academy of Sciences
10:08	<b>WEXO05</b> Effect of Source Tuning Parameters on the Plasma Potential of Heavy Ions and its Influence on the Longitudinal Optics of the High Current Injector	Gerard Oscar Rodrigues – IUAC, India
<b>WEYO</b> 11:00 - 12:30	<b>Ion Beam Extraction &amp; Optics</b> Chair: - Hannu Koivisto	
11:00	<b>WEYO01</b> The Einzel Lens Longitudinal Chopper	Ken Takayama – KEK, Japan
11:22	<b>WEYO02</b> Experimental Results: Charge-state and Current-density Distribution at the Plasma Electrode	Lauri Panitzsch – Christian Albrechts University, Kiel, Germany
11:44	<b>WEYO03</b> Ion Beam Extraction from Magnetized Plasma	Peter Spaedtke – GSI Darmstadt, Germany
12:06	Extra discussion time for all papers in Ion Beam Extraction & Optics and Ion Production & Modelling sessions	

# Program

## Wednesday, 26 September 2012 (con'd)

<b>WEZO</b> 14:00 - 15:06	<b>New Developments &amp; Next Generation Sources</b> <b>Chair: Friedhelm Ames</b>	
14:00	<b>WEZO01</b> Status of the SEISM Experiment	Thierry Lamy – LPSC, Grenoble, France
14:22	<b>WEZO02</b> Design of new 18 GHz ECR Ion Source	Kazutaka Ozeki – RIKEN Nishina Center, Japan
14:44	<b>WEZO03</b> Recent Results of PHOENIX V2 and New Prospects with PHOENIX V3	Christophe Peaucelle – Institut de Physique Nucléaire de Lyon, France
15:06 - 15:50	<b>Geller Prize award / Winner's Presentation</b> <b>Chair: Thomas Thuillier – LPSC, France / LBNL, USA</b> <b>Sponsor: Antonio Villari – Pantechnik, France</b>	
<b>WEPP</b> 16:00 - 18:00	<b>Wednesday Poster Session</b> <b>The Terrace Room</b>	
16:00	<b>WEPP01</b> UV Spectral Emission Evolution during Breakdown in a 2.45 GHz ECR Hydrogen Plasma	Ana Megía-Macías – ESS Bilbao, Spain
	<b>WEPP02</b> Relationship of Performance and RF Resonance Modes	Atsushi Kitagawa – NIRS, Japan
	<b>WEPP03</b> Plasma Instability in the Afterglow of ECR Discharge Sustained in a Mirror Trap	Vadim Skalyga – Institute of Applied Physics, Russian Academy of Sciences
	<b>WEPP04</b> Geant4 Simulation of the X-ray Shielding for a High Performance ECR Ion Source	Byoung Chul Kim – IBS, Republic of Korea
	<b>WEPP05</b> Status of the 18 GHz Superconducting ECRIS Construction at NFRI	Hyun-Jong You – National Fusion Research Institute, Republic of Korea

## Wednesday, 26 September 2012 (con'd)

	<b>WEPP06</b> Energy Dispersive X-ray Spectroscopy for ECR Plasma Diagnostics	Martin Kreller – DREEBIT GmbH, Germany
	<b>WEPP08</b> Emittance Measurements for RIKEN 28 GHz SC-ECRIS	Kazutaka Ozeki – RIKEN, Japan
	<b>WEPP09</b> Emittance Measurements for the Intense Heavy Ions Beams Formed by the Gasdynamic ECR Multicharged Ion Source at 37.5 GHz	Alexander Sidorov – Institute of Applied Physics, Russian Academy of Sciences
	<b>WEPP11</b> Study of Extraction and Transport for 18 GHz SC-ECRIS at RCNP	Tetsuhiko Yorita – Osaka University, Japan
	<b>WEPP12</b> Magnetic Field Measurement of the Permanent Hexapole Magnet for an 18 GHz ECRIS at NFRI	Soouk Jang – National Fusion Research Institute, Republic of Korea
	<b>WEPP13</b> Update of the LECR4-Dragon Ion Source	Wang Lu – IMP, Lanzhou, China
	<b>WEPP14</b> An Advanced Injection System of Light Ions (AISLI) for Dielectric Wall Accelerator	Haitao Ren – Peking University, China
	<b>WEPP15</b> Metal Ion Beam Production with Improved Evaporation Ovens	Klaus Tinschert – GSI Darmstadt, Germany
	<b>WEPP16</b> Experimental Studies on the ALISES Ion Source at CEA Saclay	Olivier Tuske – CEA Saclay, France
	<b>WEPP17</b> A Multi-Sample Changer Coupled to an ECR Source for AMS Experiments	Richard Vondrasek – ANL, USA
	<b>WEPP18</b> CARIBU ECR Charge Breeder Background Studies	Richard Vondrasek – ANL, USA
19:00 - 23:00	<b>Workshop Dinner</b> <b>Waterfront Restaurant</b>	

# Program

## Thursday, 27 September 2012 Australian National Maritime Museum

<b>THXO</b> 08:50 - 10:20	<b>Superconducting Sources</b> Chair: - Guillaume Machicoane	
08:50	<b>THXO01</b> Optimization of the New SC Magnetic Structure with Hybrid Magnet	Daniel Xie – IMP, Lanzhou, China
09:14	<b>THXO02</b> Current Developments of the VENUS Ion Source in Research and Operations	Janilee Yvette Benitez – LBNL, USA
09:36	<b>THXO03</b> Recent RIKEN 28 GHz SC-ECRIS Results	Yoshihide Higurashi – RIKEN Nishina Center, Japan
09:58	<b>THXO04</b> SECRAL status and future challenge	Hongwei Zhao – IMP, Lanzhou, China
<b>THYO</b> 11:00 - 12:30	<b>Charge Breeding &amp; Radioactive Ion Beams</b> Chair: - Takahide Nakagawa	
11:00	<b>THYO01</b> Operation of an ECRIS Charge State Breeder at TRIUMF	Friedhelm Ames – TRIUMF, Canada
11:22	<b>THYO02</b> LPSC PHOENIX ECR Charge Breeder Beam Optics and Efficiencies	Thierry Lamy – LPSC, Grenoble, France
11:44	<b>THYO03</b> Design Status of FRIB ECR Ion Sources and Low Energy Beam Transport	Guillaume Machicoane – FRIB, Michigan State University Cyclotron Laboratory, USA
12:06	<b>THYO04</b> Performance of the ANL ECR Charge Breeder with Low Mass Beams	Richard Vondrasek – ANL, USA
13:30 - 18:00	Excursions	

## Friday, 28 September 2012 Australian Nuclear Science and Technology Organisation

08:30	Meet at ANMM for coach to ANSTO	
09:20	Introduction to ANSTO Professor John Dodson – ANSTO	
<b>FRXA</b> 09:40 - 10:50	<b>New Developments &amp; Status Reports</b> Chair: - Giovanni Ciavola	
09:40	<b>FRXA01</b> High Intensity Beam Production at CEA/Saclay for the IFMIF Project	Raphael Gobin – CEA/Saclay IRFU, France
10:02	<b>FRXA02</b> All Permanent Magnet ECR Ion Source Development and Operation Status at IMP	Liangting Sun – IMP, Lanzhou, China
10:24	<b>FRXA03</b> Laser Ablation of Actinides into an Electron Cyclotron Resonance Ion Sources for Accelerator Mass Spectroscopy	Tala Palchan – ANL, USA
<b>FRYA</b> 11:10 - 12:16	<b>Status Reports</b> Chair: - Thierry Lamy	
11:10	<b>FRYA01</b> ECRISs at GANIL Today and Tomorrow	Pascal Jardin – GANIL, France
11:32	<b>FRYA02</b> Status of ECR Ion Sources for Carbon-ion Radiotherapy in Japan	Atsushi Kitagawa – NIRS, Japan
11:54	<b>FRYA03</b> ECRIS Related Research and Development Work at JYFL and Some Future Prospects	Hannu Koivisto – JYFL, Finland
	<b>Workshop Close</b>	
12:16 - 12:46	<b>Closing remarks</b>	
14:30 - 16:30	ANSTO Tour	

TUX001

## **Coupling Microwave Power into ECR Ion Source Plasmas at Frequencies above 20 GHz**

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**Claude M Lyneis, Janilee Yvette Benitez, Markus Michael Strohmeier**  
(LBNL, Berkeley, California)

Electron Cyclotron Resonance (ECR) ion sources have been built to operate at frequencies from 5 GHz to 28 GHz and typically use a plasma chamber that serves as a multi-mode cavity. For small sources operating at 6 to 14 GHz cavity mode-like behavior has been reported. In these cavities the vacuum mode density is low enough that it may be that the RF power distribution can be understood in terms of excitation of a few modes. The large superconducting ECR ion sources, such as VENUS, operating at higher frequencies have a much greater mode density and very strong damping from plasma microwave adsorption. In this type of source, how the RF is launched into the plasma chamber will strongly affect the microwave coupling and the chamber walls will be less important. The VENUS source uses round over-moded TE<sub>01</sub> mode waveguide to couple to the plasma, while most modern fusion devices use quasi-gaussian HE<sub>11</sub> waves for injection into plasmas. In this paper we will describe the potential advantages of applying this technology to superconducting ECR ion sources as well as designs for doing so with VENUS.

TUX002

## An Experimental Study of ECRIS Plasma Stability and Oscillation of Beam Current

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Olli Tarvainen, Hannu Koivisto, Jani Komppula, Ville Toivanen (JYFL, Jyvaskyla), Claude M Lyneis, Markus Michael Strohmeier (LBNL, Berkeley, California)

The stability of oxygen ion beams extracted from ECR ion sources has been studied with the superconducting ion source VENUS at LBNL and with the A-ECR type 14 GHz ECRIS at JYFL. Discrete Fourier transform has been used for characterizing beam current oscillations in kHz range exhibited by both ion sources. The effect of source parameters on the frequency and amplitude of the oscillations is discussed. It was found that double frequency heating affects the oscillation frequency, biased disc can be used to mitigate the amplitude of beam current fluctuations, increasing B-minimum results to pronounced instabilities and operating the ion source with significantly higher mirror ratio than suggested by ECRIS scaling laws yields the most stable ion beams. It is argued that the observed beam current fluctuations are correlated with plasma instabilities. A 'roadmap' for identifying the plasma instability mechanisms responsible for beam current fluctuations is presented.

TUX003

## Two-frequency Heating Technique for Stable ECR Plasma

**Atsushi Kitagawa**, Masayuki Muramatsu (NIRS, Chiba-shi), Noriyuki Sasaki, Wataru Takasugi (AEC, Chiba), Sandor Biri, Richárd Rácz (ATOMKI, Debrecen), Arne G. Drentje (KVI, Groningen), Takashi Fujita (National Institute of Radiological Sciences, Chiba)

As a method to improve highly charged ion production, a technique to feed multiple microwaves with different frequencies is well-known. However the reason is not made sufficiently clear. Our group studied with two frequencies close together with a power of 600 W over by 18 GHz NIRS-HEC ECR ion source installed in the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS). As a result, it was revealed that the improvement of output beam current depends on the total power. In this case it seems that the two-frequency heating technique carries the advantage that the plasma instability at high microwave power is relieved. The effectiveness of an additional microwave depends on its frequency. It is necessary to optimize an additional frequency precisely; several tens MHz step against 18 GHz. The optimized frequency is directly influenced by the magnetic configuration. The necessary requirements for an additional microwave and the procedure of optimization in order to obtain a large advantage will be discussed.



TUX004

## Ultra-High Sensitivity Determination of $^3\text{He}/^4\text{He}$ Abundances in Helium by Accelerator Mass Spectrometry for Neutron Lifetime Measurement

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Hans Pieter Mumm, Michael Huber (NIST, Gaithersburg, Maryland), Chithra Nair, Tala Palchan, Richard Claude Pardo, Ernst Rehm, Robert Scott, Richard Vondrasek (ANL, Argonne), Christopher O'Shaughnessy (MPI, Muenchen), Craig Huffer, Paul R. Huffman, Karl Schelhammer (North Carolina State University, Raleigh, North Carolina), Michael Paul (The Hebrew University of Jerusalem, Jerusalem), Liang Yang (University of Illinois, Urbana), William Bauder, Philippe Collon (University of Notre Dame, Indiana)

The neutron lifetime is important in studies of primordial  $^4\text{He}$  abundance and fundamental interactions. Ultra-cold neutrons are stored in a superfluid  $^4\text{He}$  magnetic trap and the neutron lifetime determined via beta-activity decay; extreme  $^4\text{He}$  isotopic purity is required to reduce neutron capture on  $^3\text{He}$ . We report  $^3\text{He}/^4\text{He}$  measurements by accelerator mass spectrometry using a RF source and the ECRIS-ATLAS facility. ATLAS was tuned using  $^{12}\text{C}^{4+}$  ions produced in the ECRIS and accelerator components scaled to  $^3\text{He}^+$ . To reduce atmospheric  $^3\text{He}$  contamination,  $^3\text{He}^+$  ions were produced in a RF He discharge source;  $\text{H}_3^+$  ions from high-purity hydrogen alternately served for transmission monitoring. Mass-analyzed ions were transported through the (passive) ECR and accelerated to 8 MeV.  $\text{H}_3^+$  and  $\text{DH}^+$  ions were eliminated by dissociation in a Au foil. Exiting ions were dispersed in a magnetic spectrograph and  $^3\text{He}^{2+}$  ions counted.  $^3\text{He}/^4\text{He}$  measurements in isotopically purified  $^4\text{He}$ , used in the lifetime apparatus, and in He samples ( $^3\text{He}/^4\text{He} = 1\text{e-}9$  to  $1\text{e-}13$ ) prepared by dilution with deep-well He ( $^3\text{He}/^4\text{He} \sim 2\text{e-}7$ ) will be discussed. Lowest ratios measurable are  $\sim 1\text{e-}14$ , limited by ion source or sample background.

This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and NSF grant PHY-0855593.

TUYO01

## Experimental Study of Temperature and Density Evolution During Breakdown in a 2.45 GHz ECR Plasma

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**Oswaldo Daniel Cortázar**, Ana Megía-Macías, Álvaro Vizcaíno-de-Julián  
(ESS Bilbao, LEIOA)

An experimental study of temperature and density evolution during breakdown in off-resonance ECR hydrogen plasma by time resolved Langmuir probe diagnostic is presented. Under square 2.45 GHz microwave excitation pulses with a frequency of 50 Hz and relative high microwave power, unexpected transient temperature peaks that reach 18 eV during 20 microsec are reported at very beginning of plasma breakdown. Decays of such peaks reach final stable temperatures of 5 eV at flat top microwave excitation pulse. Evidence of interplay between incoming power and duty cycle giving different kind of plasma parameters evolutions engaged to microwave coupling times is observed. Under relative high power conditions where short microwave coupling times are recorded, high temperature peaks are measured. However, for lower incoming powers and longer coupling times, temperature evolves gradually to a higher final temperature without peaking. On the other hand, the early instant where temperature peaks are observed also suggest a possible connection with preglow and superadiabatic processes during breakdown in ECR plasmas.

TUYO02

## **New Conception of the Control of Plasma Transversal Losses, Caused by MHD Instabilities, in Open Mirror Magnetic Traps: Experiments on SMIS 37 Setup**

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**Alexander Sidorov, Ivan Izotov, Sergey Razin (IAP/RAS, Nizhny Novgorod)**

This work is a continuation of the experiments described in [1, 2] and aimed at the investigation of the new conceptions of MHD stabilization of plasma in open axisymmetric traps, specifically, it is aimed at the investigation of the shear flow influence on the transport control in open mirror traps. As in previous experiments, shear flow was created by limiter-electrode with bias potential according to the vacuum chamber. Plasma density structure in radial and azimuthal directions was studied. Mode structure of the perturbations was investigated. Substantial sharp shift of the plasma density maximum to the system axis with bias potential growth was demonstrated. It was shown, that the value of the bias potential that corresponds to the plasma density profile shift grows with the magnetic field growth that can be interpreted as the electron temperature growth. Some theoretical estimations of the influence of the transversal losses decrease on plasma parameters were made.

[1] A.Sidorov, P.Bagryansky, A.Beklemishev et al. Trans. Fusion Sci. and Technology, 59, 112, (2011).

[2] I.Izotov, S.Razin, A.Sidorov et al. Rev. Sci. Instrum., 83, 02A318 (2012).

This work was partially performed in the framework of the Federal Targeted Program 'Scientific and Educational Personnel of the Innovative Russia' for 2009-2013

TUYO03

## Secondary-electron-enhanced Plasma as an Alternative to Double/Variable-frequency Heating in ECRIS

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**Kurt Ernst Stiebing** (IKF, Frankfurt-am-Main), **Serban Dobrescu**,  
**Leon Schachter** (IFIN, Magurele- Bucuresti)

As “double frequency heating” (DFH) now has become the method of choice to optimize the output from the newest generation ECRIS, it was a challenge to compare this method with the comparatively cheap method of “metal dielectric” (MD) structures introduced into the plasma chamber, which has also proven to strongly enrich the plasma with electrons that are effectively trapped and heated. Two RF-systems have been launched to the 14 GHz ECRIS, however, not allowing RF-differences as large as 1.5 GHz as demanded for DFH. Therefore the source was operated in a “frequency tuning” mode (FT) by optimizing the frequency difference by the output of Ar<sup>14+</sup> ions. The data without and with MD-configuration are compared and related to data for the DFH. On the basis of Bremsstrahlung radiation spectroscopy and charge state analysis, it turned out that the FT-mode does not change the source performance substantially. The measured effects are in the order of 20% to 30% as reported elsewhere. In contrast to this, the enhancement gained by the MD method is much higher. The measured enhancement ratios even surpass those reported for real double frequency heating.

TUYO04

## Neutral Gas Temperature Measurements of a Radio Frequency Micro-thruster

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Amelia Greig, Rod Boswell, Christine Charles, Rhys Hawkins (SP3, Canberra), Mark Bowden, Yvonne Sutton (The Open University, Milton Keynes)

A radio frequency (13.56 MHz) capacitively coupled cylindrical argon plasma discharge was analysed using optical emission spectroscopy (OES) for various powers and pressures in the ranges 10 W to 40 W and 0.5 Torr to 5 Torr. Trace amounts of nitrogen were added to the discharge to estimate the temperature of the neutrals using rovibrational band matching of the 2nd positive system of nitrogen and the 1st negative system of nitrogen ions. Comparing simulated computer generated spectra of these bands to experimentally measured spectra determined the rotational and vibrational temperatures of the nitrogen, from which the temperature of the neutrals was inferred by assuming the rotational temperature was the same as the neutral gas temperature.

TUZ001

## Beam Extraction Results with KAERI 14.5 GHz ECR Ion Source

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Byung-Hoon Oh, Dae-Sik Chang, Chul-Kew Hwang, Sang-Ryul In, Seung Ho Jeong, Jeong-Tae Jin, Tae-Seong Kim, Cheol Ho Lee, Kwang-Won Lee (KAERI, Daejeon), Eun-San Kim, Chang Seog Seo (IBS, Daejeon)

A 14.5 GHz electron cyclotron resonance ion source has been designed and fabricated at KAERI (Korea Atomic Energy Research Institute) to produce multi-charged ion beams (particularly  $C^{6+}$  ion beams) for medical applications. During the first beam extraction experiments with the developed ion source, it was found that  $C^{4+}$  beam of 15  $\mu A$  and  $Ar^{15+}$  beam of 1  $\mu A$  were the optimized beam current. A big current loss was made along the beam transport path from the ion source to the entrance port of an analyzing magnet because of long beam line and small acceptance of the magnet. A new Einzel lens is added in the beam line to minimize the beam loss, and the second beam extraction experiments have been made. In this paper the beam experimental results with the KAERI ion source, including the hard X-ray spectrum from the ECR plasma and the emittance measurement results of carbon beam, will be discussed.

TUZO02

## The Surprising Effect of Limiters and why Multiple Beamlets Emerge from one Pepper Pot Hole

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Herman R. Kremers, Johannes P.M. Beijers, Sytze Brandenburg, Vladimir Mironov, Jan Mulder, Suresh Saminathan (KVI, Groningen)

At KVI a pepper pot emittance meter has been installed in the image plane of the charge state analyzer of the AECR source. With this instrument the full 4D phase space distributions are measured. These distributions show complex patterns, which have been successfully modeled using initial distributions calculated with a PIC simulation code and second order ion optics calculated with COSY Infinity 9.1. The model explains the complex angular distributions that result in multiple beamlets emerging from individual pepper pot apertures and 'holes' in the 4D phase space distribution caused by collimators. Measurements and calculations for a 24.6 keV  $^4\text{He}^+$  beam will be presented. We will also show that in the  $x'$ - $y'$  projection correlations can be measured which relate to higher order aberration functions similar as in higher order optical calculations. These results clearly demonstrate that an emittance meter measuring the full 4D phase space distribution is an essential instrument to study and understand the behavior of the large emittance, low energy beams extracted from an ECR ion source in a beam guiding system.

TUZO03

## **New Extraction Design for the JYFL 14 GHz ECRIS**

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**Ville Toivanen,** Taneli Kalvas, Hannu Koivisto, Jani Komppula, Olli Tarvainen  
(JYFL, Jyväskylä)

A new extraction system has been designed and constructed for the JYFL 14 GHz ECRIS at the Department of Physics, University of Jyväskylä (JYFL).

The goal of the new design is to improve the performance of the ion source and increase the transmission efficiency of the low energy beam transport and the accelerator. The new extraction system is designed to be able to handle higher beam currents, yield better beam quality and offer more tuning flexibility. The design was made with the aid of simulations performed with the IBSimu code. The suitability of the code for this task was verified by simulating the old extraction system and good agreement between simulations and measurements was achieved. The new extraction system has been constructed, installed and tested. The new design, simulations and the first measurement results will be presented.

VT acknowledges the financial support of the Ehrnrooth foundation.



TUZO04

## Space Charge Compensation Measurements of Multicharged Ion Beams Extracted from an ECR Ion Source

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**Daniel Winklehner** (LBNL, Berkeley, California), Dallas Gene Cole, Daniela Leitner, Guillaume Machicoane, Larry Tobos (NSCL, East Lansing, Michigan)

Space charge compensation\* due to the interaction of the beam with residual gas molecules is a well-known phenomenon for high current injector beam lines. For beam lines using mostly magnetic focusing elements and for pressure above 1E-6 mbar, full neutralization has been observed. However, due to the low pressure required for the efficient transport of high charge state ions, beams in ECR injector lines are typically only partly neutralized. With the performance increase of the next generation ECR ion sources it is possible to extract tens of mA of beam current. In this high current regime, non-linear focusing effects due to the space-charge potential of the beam become more and more important. In order to develop a realistic simulation model for low energy beam transport lines, it is important to estimate the degree of space charge compensation. In this contribution we report on measurements of the beam potential (and neutralization), performed after the extraction region of the ECR ion source, in dependence of the base pressure in the beam line and other source parameters using a Retarding Field Analyzer (RFA). Results are discussed and compared to simulations.

\*When the beam interacts with the residual gas, electrons are separated from gas molecules and accumulate inside the beam envelope, thereby compensating the space-charge (aka neutralization)

TUPP01

## **Quantitative Determination of $^{146}\text{Sm}/^{147}\text{Sm}$ Ratios by Accelerator Mass Spectrometry with an ECR Ion Source and Linear Acceleration for $^{146}\text{Sm}$ Half-Life Measurement**

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**Norikazu Kinoshita** (UTTAC, Tsukuba, Ibaraki), Brad DiGiovine, John Philip Greene, Dale Henderson, Cheng-Lie Jiang, Scott T. Marley, Richard Claude Pardo, Ernst Rehm, Robert Scott, Richard Vondrasek (ANL, Argonne), Takashi Nakanishi, Akihiko Yokoyama (Kanazawa University, Kanazawa), Catherine Deibel (MSU, East Lansing, Michigan; ANL, Argonne), Michael Paul (The Hebrew University of Jerusalem, Jerusalem), Philippe Collon, Yoav Kashiv, Daniel Robertson, Chris Schmitt, Xiaodong Tang (University of Notre Dame, Indiana)

The alpha-decaying  $^{146}\text{Sm}$  nuclide is used for chronology of the Solar System and silicate mantle differentiation in planets. We performed a new determination of  $^{146}\text{Sm}$  half-life by measuring  $^{146}\text{Sm}/^{147}\text{Sm}$  alpha activity and atom ratios in  $^{147}\text{Sm}$  activated via (g,n), (n,2n) and (p,2n) reactions and obtained a value (68 Myr), smaller than that adopted so far (103 Myr), with important geochemical implications\*. The experiment required determination of  $^{146}\text{Sm}/^{147}\text{Sm}$  ratios by high-energy (6 MeV/u) accelerator mass spectrometry to discriminate  $^{146}\text{Sm}$  from isobaric  $^{146}\text{Nd}$  contaminant. Activated Sm targets were dissolved, chemically purified and reconverted to metallic Sm. Sputter cathodes, made by pressing the Sm metal into high-purity Al holders, were used to feed the Argonne ECR ion source.  $^{146}\text{Sm}^{22+}$ ,  $^{147}\text{Sm}^{22+}$  ions were alternately injected and accelerated with the ATLAS linac by proper scaling of ion source and accelerator components. A tightly-fitted quartz cylindrical liner was inserted in the ECR plasma chamber to reduce contamination from the walls.  $^{146}\text{Sm}$  ions were eventually counted in a gas-filled magnet and  $^{147}\text{Sm}$  ions either measured as charge current or counted after proper attenuation.

\* N. Kinoshita et al., Science 334, 1614 (2012)

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## TUPP02

### Performance of a New Compact ECR Ion Source for Stable Isotope Mass Spectrometry

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**David Taylor Button**, Michael Hotchkis (ANSTO, Menai), Bruce Greenlees (ANSTO, Menai, New South Wales), Charles Magee, Ed Roberts (ASI, Fyshwick)

We have developed a mass spectrometry system, known as the IRMS++, for measurement of isotope ratios of the light elements carbon, nitrogen and oxygen, for applications in earth and environmental sciences. By generating multiply-charged atomic ions from molecular gaseous species, such as water vapour or carbon dioxide gas, isotopes can be measured free from molecular interferences [1]. The IRMS++ uses an ECR ion source specially designed for this purpose [2]. The new ECRIS design incorporates improvements to the microwave system, with special attention to generation of the cavity mode which is expected to couple most effectively to electrons in the ECR resonance zone. Also this design has an improved magnetic field structure to optimise performance at 7GHz. In this paper we will report initial performance tests of the new ion source.

[1] Hotchkis et al., Rapid Commun. Mass Spectrom. 22(2008)1408.

[2] Button et al., Rev. Sci. Instr., 83(2012)02A322.

TUPP03

## Integration of a Third Ion Source for Heavy Ion Radiotherapy at HIT

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**Tim Winkelmann, Alexander Büchel, Rainer Cee, Andreas Gaffron, Thomas Haberer, Jörg Martin Mosthaf, Bernd Naas, Andreas Peters, Jochen Schreiner (HIT, Heidelberg)**

HIT is the first European hospital based facility for scanned proton and heavy ion radiotherapy. In 2009 the clinical operation started, since then more than 800 patients were treated in the facility. In a 24/7 operation scheme two 14.5 GHz electron cyclotron resonance ion sources are routinely used to produce protons and carbon ions. In the near future a helium beam for regular patient treatment is requested. The modification of the low energy beam transport line (LEBT) for the integration of a third ion source into the production facility was done in winter 2011. For beam quality improvement with a smaller emittance at the same current we designed and tested a new extraction system at the testbench and equipped the source for protons and helium with this optimized system. This paper will present results of the LEBT modification and gives an outlook to further enhancements at the HIT ion source testbench.

## TUPP04

### Design of New Compact ECR Ion Source for Production of Various Ions

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**Masayuki Muramatsu**, Satoru Hojo, Yoshiyuki Iwata, Ken Katagiri, Atsushi Kitagawa, Yukio Sakamoto, Shinji Sato (NIRS, Chiba-shi), Arne G. Drentje (KVI, Groningen), Takashi Fujita (National Institute of Radiological Sciences, Chiba)

Compact ECR ion source with all permanent magnets, so called Kei2, was developed for high energy carbon ion therapy facility at National Institute of Radiological Sciences. Kei2 source was design for production of only carbon ion for medical treatment. A copy of Kei2, so called KeiGM is used for Gunma University. Kei series are optimized for carbon ion production. In order to produce various ion beams for research, we design a new compact ECR ion source, so called Kei3. Kei3 is designed based on previous Kei series. In addition, there are three important points:

- 1) Movable beam extraction system for various extraction current densities,
- 2) An evaporator and MIVOC method for production of ions from solid materials and metal, and
- 3) Biased disk method and double frequency heating method for heavier ions.

Same permanent magnets and microwave system will be used for easy maintenance and the cost effectiveness. Design of the Kei3 source will be described in this paper.

TUPP05

## Charge-breeding at the Texas A&M University Cyclotron Institute

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**Donald Philip May** (Texas A&M University Cyclotron Institute, College Station, Texas), **Juha Erik Arje** (JYFL, Jyvaskyla), **Gabriel Tabacaru** (Texas A&M University, College Station)

The Cyclotron Institute of Texas A&M University is currently involved in an upgrade that is intended to produce beams of radioactive ions suitable for injection into the K500 superconducting cyclotron. As an integral part of this upgrade an electron-cyclotron-resonance ion source (CB-ECRIS) has been specially constructed by Scientific Solutions of San Diego, California for charge-breeding. This CB-ECRIS operates at 14.5 GHz and incorporates a hexapole of the Halbach style. Since radial injection of microwave power is ruled out, this presents special problems for the axial injection of low-charge-state ions for charge-breeding. Efforts at charge-breeding with stable ions will be presented as well as plans for the injection of low-charge-state, radioactive ions from cyclotron-driven ion guides, one for light radioactive ions and one for heavy radioactive ions.

TUPP07

## **Upgrading of the CAESAR Ion Source at INFN-LNS**

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**Luigi Celona, Giuseppe Castro, Maurizio Castro, Francesco Chines, Giovanni Ciavola, Santo Gammino, David Mascali (INFN/LNS, Catania)**

The CAESAR source is operating at INFN-LNS since 1999 and it has provided the most of light ions for the K-800 Superconducting Cyclotron, whereas the SERSE source is mainly devoted to the production of highly charged heaviest ions. Anyway, since the beginning the source behavior appeared to be not satisfactory in terms of the beam transmission to the Cyclotron and then the extraction system has been redesigned in order to decrease the emittance. The main features of the calculations carried out with KOBRA3D are described. Recently the injection section has been also re-designed, because of the poor results obtained when operating CAESAR (too high microwave power reflection and poor coupling to the plasma). The new setup has an improved axial confinement due to the insertion of adequate iron plugs and the coupling has been experimentally tested to be effective up to 18 GHz. The paper will describe the major mechanical design features together with the results achieved.

TUPP08

## Design Report of the AISHA Ion Source for Hadron Therapy Facilities

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**Giovanni Ciavola** (CNAO Foundation, Milan; INFN/LNS, Catania), **David Mascali** (CSFNSM, Catania; INFN/LNS, Catania), **Luigi Celona**, **Santo Gammino** (INFN/LNS, Catania)

Different facilities for hadrontherapy have been built or designed in the recent past and Italy is present in the field either with synchrotron-based and with cyclotron-based facilities. For both types of accelerators the availability of high brightness multiply charged ion beams is essential and R&D efforts in this subject are increasing. In particular at the CNAO, proton and carbon ion beams will be accelerated up to 400 AMeV by a synchrotron and the beam injection is guaranteed by two identical ECR sources of the SUPERNANOGAN family modified according to the specifications we set. Optimisation of beam emittance and intensity is of primary importance to obtain the necessary current in the RFQ-LINAC and future facilities may require much better performances in terms of beam brightness than the ones provided by such commercial ECRIS. A hadron therapy center is going to be built in Catania and the R&D related to the injector has already started within the frame of a collaboration between the Regional Authority and INFN. The results of the research carried out at INFN-LNS will be presented along with the design of a relatively compact ECR ion source operating at 18 GHz, named AISHA.



## TUPP09

### **R&D Plan of the ECR Ion Sources for RISP**

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**In-Seok Hong,** Byung Cheol Kim (IBS, Daejeon), Eun-San Kim (KNU, Deagu)

Rare isotope science project(RISP), which is a heavy ion accelerator program in Korea, consists of the isotope separation on-line (ISOL) facility and the in-flight fragmentation (IFF) facility. At least 3 ECR ion sources are needed to provide the heavy ions such as uranium ions with ISOL and IFF. 28GHz superconducting ECR ion sources have been considered to meet the requirement of ISOL and IFF. Detailed conceptual design and R&D plan of the ion source will be presented.

This work is supported by MEST in Korea government.

TUPP10

## **Operational Experience with the GTS-LHC Ion Source and Future Developments of the CERN Ion Injector**

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**Detlef Kuchler, Giulia Bellodi, Alessandra Maria Lombardi, Michael O'Neil, Richard Scrivens, Joshua Tobias Stafford-Haworth (CERN, Geneva), Rainer Wolfgang Thomaе (iThemba LABS, Somerset West)**

Since 2010 the GTS-LHC source delivers lead ions for heavy ion physics at the LHC. Several modifications allowed improving the source reliability and the beam stability. The attempts to improve the beam intensity were less successful. The different modifications and actual performance figures will be presented in this paper. In addition to the heavy ion physics program of the LHC new ion species will be requested for different experiments in the future. The fixed target experiment NA61 requires primary Argon and Xenon beams. And a future radio-medical facility asks for light ions in the range Helium to Neon. Approaches to prepare these beams and to modify the ion injector towards a light ion front end are presented.

TUPP11

## **The Status Report of Superconducting ECR Ion Source in KBSI**

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**Byoung Seob Lee**, Seyong Choi, Jung-Woo Ok, Jin Yong Park, Mi-Sook Won, Jang-Hee Yoon (Korea Basic Science Institute, Busan), Eun-San Kim (IBS, Daejeon; KNU, Deagu), JungBae Bahng (Kyungpook National University, Daegu)

The development of 28 GHz electron cyclotron resonance ion source is being progressed by the Korea Basic Science Institute. The manufacturing of superconducting coils, plasma chamber, RF system were completed and is being tested. Also, the construction of low energy beam transmission system is in progress. In this report, test results of RF system, plasma chamber without magnetic field and the design related to low energy beam transmission system will be presented. We will construct the 28 GHz superconducting cyclotron resonance ion source until 2012 in Busan. We hope to generate 1st ion beam in December.

TUPP12

## Design of Web-based Interface to RIKEN 28 GHz Superconducting ECR Ion Source and the Future Plan

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**Akito Uchiyama** (Sokendai, Ibaraki), **Kazuro Furukawa** (KEK, Ibaraki), **Yoshihide Higurashi**, **Misaki Komiya**, **Takahide Nakagawa**, **Kazutaka Ozeki** (RIKEN Nishina Center, Wako)

A new RIKEN 28 GHz superconducting ECR ion source (28 GHz-ECRIS) was constructed in 2009 in order to increase the intensity of Uranium ion beam for RIKEN RI beam factory project(RIBF). For effective and stable operation of the 28 GHz-ECRIS, its client system should have an user-friendly man-machine interface. The ECRIS control system was constructed with the Experimental Physics and Industrial Control System (EPICS) as well as RIBF control system. As a result, it was successful to provide the useful clients, such as the operation GUI panels, the XY chart application, and the data acquisition system in EPICS-based system. On the other hand, to keep beam quality from 28 GHz-ECRIS for a long beam service term, it should be possible to operate the ECRIS by members of ion source team at any time. In order to relieve concern in the overseas business trip of members of ion source team, we designed a real-time web-based client system using WebSocket\*, which is a new protocol presented by Internet Engineering Task Force (IETF). In this paper, we report the system and development status in detail.

\*I. Fette and A. Melnikov. The WebSocket Protocol, IETF HyBi Working Group. 2011.

## TUPP13

### Development of Intense Proton Beam ECR Ion Source at IMP

Zimin Zhang, Zhanwen Liu, Hongyi Ma, Liangting Sun, Yao Yang, Wenhui Zhang, Xuezheng Zhang, Hongwei Zhao (IMP, Lanzhou)

Since 1997, there have been two ECR ion sources for producing intense proton beam developed at Institute of Modern Physics (IMP). In 1999, a high current 2.45 GHz ECR proton source for Lanzhou university neutron generator, was constructed and tested at IMP. A mixed ion ( $H_1^+ + H_2^+ + H_3^+$ ) beam current of 110 mA with CW mode was delivered from a single aperture of 6mm diameter with microwave power of 600 W at the extraction voltage of 22 kV. Recently a new pulsed proton source has been designed and built at IMP for the CPHS (Compact Pulse Hadron Source) facility in Tsinghua University. Now this source is under commissioning for 60 mA proton beam with 50 keV energy. The long time running stability and beam emittance have been tested and the results are well up to the requirements of CPHS. In this paper, after a short review of the proton ion source for Lanzhou University, the design and test results of the CPHS proton source as well as the LEBT will be presented. The design of the proton ion source and the LEBT for the Chinese ADS project will also be discussed in the contents.

TUPP14

## **Beam Experiments with the Grenoble Test Electron Cyclotron Resonance Ion Source at iThemba LABS**

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**Rainer Wolfgang Thomae**, Jacobus Conradie, Dirk Theunis Fourie (iThemba LABS, Somerset West), Detlef Kuchler (CERN, Geneva)

At iThemba Laboratory for Accelerator Based Sciences a copy of the so-called Grenoble Test Source (GTS) for the production of highly charged ions is installed. The source in combination with the K-200 cyclotron delivers high energy, high intensity beams for nuclear physics experiments. In this paper we present beam experiments with the GTS at iThemba LABS, in which the results of CW, pulsed and afterglow operation for different bias disc voltages and positions are compared.

TUPP15

## Test Results of Superconducting Magnet System for 28 GHz Electron Cyclotron Resonance Ion Source at KBSI

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**Seyong Choi**, Byoung Seob Lee, Jung-Woo Ok, Jin Yong Park, Mi-Sook Won, Jang-Hee Yoon (Korea Basic Science Institute, Busan)

The superconducting magnet for a 28 GHz electron cyclotron resonance (ECR) ion source is now being developed by the Korea Basic Science Institute. The aim of the ion source is producing the fast neutrons for the radiography. The superconducting magnet for ECR ion source of KBSI is comprised of six racetrack coils for hexapole magnet and three solenoid coils. According to the design value of superconducting magnet, an axial magnetic field at the injection is going to be 3.6 T and 2.2 T at the extraction. We can control the minimum magnetic field between 0.4 and 0.8 T to generate a field gradient. A radial magnetic field on the wall of plasma chamber was designed to be 2.1 T. We have finished the winding with niobium titanium wire and each coil was put together for initial test. Superconducting magnets after assembling was vertically inserted into the cryostat to cool down using liquid helium. The coil test was performed independently to find out an error during winding process. The reasonable result of magnetic flux density at each coil was obtained comparing to the design values. We also present the test result of full operation mode by flowing the operating current simultaneously.

This work was supported by the KBSI Grant No.D32300.

TUPP16

## Conceptual Design of a Superconducting Magnet ECR Ion Source for the Korean Rare Isotope Accelerator

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Byung-Hoon Oh, Dae-Sik Chang, Chul-Kew Hwang, Sang-Ryul In, Seung Ho Jeong, Jeong-Tae Jin, Tae-Seong Kim, Cheol Ho Lee, Kwang-Won Lee (KAERI, Daejeon), Eun-San Kim, Chang Seog Seo (IBS, Daejeon)

Based on the proven technology an upgraded 28 GHz superconducting ECR ion source is suggested to produce wide range of different ion beams from proton for the ISOL to uranium for the inflight fragmentation. The suggested ion source has the following characteristics:

- 1) Shapes of minimum  $B_z$  layer can be controlled for effective electron heating with five superconducting solenoid coils.
- 2) The axial magnetic field ( $B_z$ ) higher than 4 T at the entrance of the chamber and 3 T at the exit are achieved with the five solenoid coils.
- 3) The radial magnetic field ( $B_r$ ) higher than 2.2 T is realized with saddle winding and thicker conductor for the sextupole magnets.
- 4) Two solenoid lenses, the first one in a cryo tank to minimize the beam spread by shorting the drift length after the beam extraction, and the second one at the outside of it to control the beam size and divergence in front of the entrance of the magnet, are used to improve the beam transport efficiency.
- 5) Shielding for the hard X-ray is reinforced.

With these characteristics the ion source can produce higher intensity beams with smaller beam envelopes compared with those of other present ion sources.



TUPP17

## **Installation and Operation of a 28 GHz Gyrotron for the RIKEN Superconducting ECR Ion Source**

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**Jun-ichi Ohnishi,** Yoshihide Higurashi, Takahide Nakagawa (RIKEN Nishina Center, Wako)

The RIKEN 28-GHz ECRIS uses a gyrotron microwave source fabricated by Mitsubishi Electric Corporation. The maximum output power is 10 kW. The gyrotron produces TE<sub>02</sub>-mode microwaves, which are converted into the TE<sub>01</sub> mode by a mode converter. In the first test on the gyrotron performed using a dummy load, we observed the 50-300 Hz ripples of ~500 W in the output power of 1-7 kW, and it was difficult to make a stable operation in the low-power. These ripples were reduced to one-tenth by stabilizing the cathode voltage and then the gyrotron could produce microwaves from < 0.5 kW stably. The operation of the ion source with the 28 GHz gyrotron was started in 2011 and the ion source supplied U and Xe beams to the RIBF for two months. The power of the microwaves fluctuated slowly in the range of 870-1250 W, which influenced the beam current from the ion source. This fluctuation was caused by a slight change of the current of the solenoid of the gyrotron depending on the room temperature. We replaced the power supply with new one which has a current stability of 10ppm per day, and stabilized the microwave power in the range of 5% in the operation of 2 kW successfully.

TUPP18

## **DECRI5-5 Ion Source for DC-110 Cyclotron Complex**

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**Andrey Efremov, Vladimir Bekhterev, Yuriy Kostyukhov, Aleksander Lebedev, Vladimir Loginov, Nikolaj Yazvitsky (JINR, Dubna, Moscow Region), Vladimir Mironov (KVI, Groningen)**

The project of the DC-110 cyclotron facility to provide applied research in the nanotechnologies (track pore membranes, surface modification of materials, etc.) has been designed by the Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (Dubna). The facility includes the isochronous cyclotron DC-110 for accelerating the intense Ar, Kr, Xe ion beams with 2.5 MeV/nucleon fixed energy. The cyclotron is equipped with system of axial injection and ECR ion source DECRI5-5, operating at the frequency of 18 GHz. The main parameters of DECRI5-5 ion source and results of the first tests are presented in this report.

WEX001

## Ion Beam Formation in Expanding Plasmas and its Application to Plasma Thrusters

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**Christine Charles** (SP3, Canberra)

For the past few decades, Direct Current (DC), radiofrequency (RF) and microwave plasma sources have been used for materials processing, materials diagnostics and electric propulsion in space. When terminated by a series of biased grids on one side, these sources can produce accelerated ion beams (which need to be neutralized) and thrust as shown by successful space missions (e.g. DC Kaufman thruster, RF Artemis thruster and microwave Hayabusa thruster). When open to vacuum or space on one side (no grid or electrode), plasma expansion occurs. The geometric and/or magnetic expansion leads to ion acceleration with sufficient electrons to provide quasi-neutrality. Applying a divergent magnetic field may lead to the spontaneous formation of an electric double layer, a sudden drop of potential within a plasma. In the laboratory, low energy large area ion beams accelerated by current-free double layers produced by RF plasma sources have been created using a variety of gases (Ar, O<sub>2</sub>, H<sub>2</sub>, CO<sub>2</sub>, Xe, Kr, CH<sub>4</sub>, NH<sub>3</sub>, N<sub>2</sub>O) and used in the production of surfaces with a variable degree of hydrophobicity and as a source of thrust in the development of new space engines.

WEX002

## Recent Developments and Electron Density Simulations at the ATOMKI 14 GHz ECRIS

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**Sandor Biri, Richárd Rác** (ATOMKI, Debrecen), **Jozsef Palinkas** (University Debrecen, Debrecen)

The 14 GHz ECR ion source of ATOMKI is a standard room-temperature ECRIS devoted for plasma diagnostic studies, for atomic physics research and also serves as a particle source with wide range of elements for surface treatments. From the beginning lots of technical modifications and developments have been carried out on the ion source. The changes aimed the increasing of the beams charge, intensity and the widening of the ion choice. Other modifications were done to develop special, non-standard operation modes or to produce peculiar plasmas or beams. Recently the original NdFeB hexapole was exchanged by a new one and new iron plugs were calculated, designed and installed at the injection side of the source. The resulted stronger magnetic trap has shown significant effect on the beam intensity and on the charge states distribution. The new magnetic configuration was re-calculated by the TrapCAD code developed by our group. The spatial movement and energy evolution of a high number of electrons were followed in the calculation. A post-calculation energy filtering carried out for the lost and non-lost electrons reveals numerous interesting and important information in 3D.

WEX003

## Numerical Modeling of Ion Production in ECRIS by using the Particle-in-Cell Method

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Vladimir Mironov, Johannes P.M. Beijers, Sytze Brandenburg (KVI, Groningen)

To better understand the physical processes in ECRIS plasmas, we developed a Particle-in-Cell code that follows the ionization and diffusion dynamics. The basic features of the numerical model are given elsewhere\*. An electron temperature of about 1 keV is needed to reproduce the experimentally observed performance of our 14 GHz ECR source. We assume that a pre-sheath is located outside the ECR zone, where the ion acceleration toward the walls occurs. Electric field inside the ECR zone is supposed to be zero. The ion production is modeled assuming the ion confinement by a ponderomotive barrier formed at the boundary of the ECR zone. The barrier height is defined by the RF radiation density at the electron resonance layer and is taken as an adjustable parameter; when the plasma becomes overdense, we set the barrier value to zero. With these assumptions, we are able to reproduce the main features of ECRIS performance, such as the saturation and decrease of highest charge state currents with increasing gas pressure, as well as response to an increase of injected RF power. Afterglow and frequency-tuning effects can be explained by introducing the ponderomotive barrier.

\*V. Mironov and J. P. M. Beijers, "Three-dimensional simulations of ion dynamics in the plasma of an electron cyclotron resonance ion source", Phys. Rev. ST Accel. Beams 12, 073501 (2009).

WEX004

## Proton Beams Formation from Dense Plasma of ECR Discharge sustained by 37.5 GHz Gyrotron Radiation

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Vadim Skalyga, Ivan Izotov, Sergey Razin, Alexander Sidorov, Vladimir Zorin (IAP/RAS, Nizhny Novgorod), Taneli Kalvas, Hannu Koivisto, Olli Tarvainen (JYFL, Jyvaskyla)

Operation of modern high power accelerators often requires production of intense beams of hydrogen ions. Newer facilities aiming at outperforming the previous generation accelerators are usually designed for higher beam currents. Meeting the demand for hydrogen ion beams with higher intensity and low transverse emittance is, therefore, becoming increasingly difficult problem. Present work is devoted to experimental investigation of proton beams production from dense plasma ( $N_e > 10^{13} \text{ cm}^{-3}$ ) of ECR discharge sustained by 37.5 GHz, 100 kW gyrotron radiation at SMIS 37 facility at IAP RAS. Different extraction system configurations were used. It was demonstrated that ultra bright proton beam with 4.5 mA current and  $0.1 \pi \cdot \text{mm} \cdot \text{mrad}$  normalized emittance (brightness =  $45 \text{ A}/(\pi \cdot \text{mm} \cdot \text{mrad})^2$ ) can be formed with 1-hole (1 mm in diameter) extraction. For production of high current beams a 13-hole extractor was used. 200 mA and  $1.1 \pi \cdot \text{mm} \cdot \text{mrad}$  normalized emittance proton beam was obtained. A possibility of further beam parameters enhancement by developing of extraction system and its power supply is discussed. It was shown that in generated proton beams  $\text{H}_2^+$  component was less than 6%.

Work was performed in frame of realization of federal targeted program "Scientific and pedagogical labor force for an innovative Russia" for 2009-2013 yy.

WEX005

## **Effect of Source Tuning Parameters on the Plasma Potential of Heavy Ions and its Influence on the Longitudinal Optics of the High Current Injector**

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**Gerard Oscar Rodrigues**, Dinakar Kanjilal, P.S Lakshmy, Abanimohan Mandal, Yaduvansh Mathur, Amit Roy (IUAC, New Delhi), Ramakrishnan Baskaran (IGCAR, Channai)

Plasma potentials for various heavy ions have been measured using the retarding field technique in the 18 GHz High Temperature Superconducting ECR ion source, PKDELIS. The influence of various source parameters viz., RF power, gas pressure, magnetic field, negative DC bias and gas mixing on the plasma potential is studied. It is observed that the plasma potentials are decreasing for increasing charge states and a mass effect is clearly observed for the ions with similar operating gas pressures. In the case of gas mixing, it is observed that the plasma potential minimises at an optimum value of the gas pressure of the mixing gas and the mean charge state maximises at this value. The energy spread arising from the plasma potential influences the longitudinal optics of the high current injector in terms of increased phase spread which deteriorates the transmission through the RFQ. Details of the measurements carried out as a function of various source parameters and its impact on the longitudinal optics are presented.

WEY001

## The Einzel Lens Longitudinal Chopper

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**Ken Takayama** (KEK, Ibaraki), **Toshikazu Adachi** (KEK, Ibaraki; Sokendai, Ibaraki), **Kwee Wah Leo** (Sokendai, Ibaraki)

The Einzel lens longitudinal chopper [1] placed just after the ECRIS has been developed for the KEK digital accelerator [2] and is being operated without trouble over more than 1 year. Propagation of a msec-long ion pulse extracted with the ECRIS extraction voltage  $V_1$ , is fully controlled by superimposing a rectangular-shape pulse voltage  $V_2$  ( $<0$ ) on the fixed Einzel lens voltage  $V_3$  ( $V_3 > V_1$ ). For most of time region ( $\sim$ msec), beam propagation is blocked, meanwhile for a time region ( $\sim$ 5 microsec), where  $V_2$  is on and  $V_2 + V_3 < V_1$ , the beam can propagate downstream under the optimized transverse matching condition. Namely, the superimposed voltage  $V_2 + V_3$  works as a gate voltage. This negative pulse voltage is produced by the solid-state switch driven Marx Generator, promising a fast rising/falling feature in the pulse profile. This chopper enjoys a lot of figure of merits originated from the fact that the beam can be handled at its minimum energy region:

- 1) low electron emission,
- 2) low voltage,
- 3) low energy X-ray, and
- 4) low cost.

This type chopper should be expected in a wide variety of ion beam applications. Comparison with other type choppers will be discussed.

[1] T. Adachi, K.W. Leo et al., "A Solid-state Marx Generator driven Einzel Lens Chopper", Rev. Sci. Inst. 82, 083305 (2011).

[2] T.Iwashita et al., "KEK Digital Accelerator", Phys. Rev. ST-AB 14, 071301 (2011).



WEY002

## Experimental Results: Charge-state and Current-density Distribution at the Plasma Electrode

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Lauri Panitzsch, Thies Peleikis, Michael Stalder, Robert Wimmer-Schweingruber (IEAP, Kiel)

We have measured the current-density in very close vicinity (15 mm downstream) of the plasma electrode of our hexapole-geometry electron-cyclotron-resonance ion source (ECRIS). For this, we equipped our 3D-movable puller electrode with a customized Faraday Cup (FC) inside. To achieve high spatial resolution we reduced the aperture of the puller electrode to only 0.5 mm. Thus, the source-region of the extracted ion beam is limited to a very small area of the plasma electrode's hole ( $d = 4$  mm). The information about the charge-state distribution and the current density in the plane of the plasma electrode is conserved in the ion beam and was scanned by remotely moving the small-aperture puller electrode (incl. FC) across the aperture of the plasma electrode. From additional  $m/q$ -measurements for the different positions we can deduce that different ion charge-states are grouped into bloated triangles of different sizes but with the same orientation in the plane of the plasma electrode with the current density peaking at the centre. This confirms simulations by various groups as well as some emittance measurements, but adds spatial resolution for the different charge-states.

WEY003

## **Ion Beam Extraction from Magnetized Plasma**

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**Peter Spaedtke, Ralf Lang, Jan Maeder, Fabio Maimone, Jon Rossbach, Klaus Tinschert (GSI, Darmstadt)**

With increasing the total extracted current for any ion source, the optimisation of the extraction system becomes more important, because of the space charge effect. Several attempts have been made in the past to simulate the extraction from an Electron Cyclotron Resonance Ion Source (ECRIS) in a correct way. Most of these attempts failed, because they were not able to reproduce the experimental results. The best model up to now is given by the following procedure: tracing the magnetic field lines through the extraction aperture, looking where these field lines are coming from; using these coordinates of the magnetic field line as starting points for ions to be extracted; the initial current of each trajectory is determined by theoretical assumptions about the plasma or by a plasma simulation; Child's law is applicable locally only in direction of the magnetic field, if no emission limited flow is present.

WEZ001

## Status of the SEISM Experiment

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Mélanie Marie-Jeanne, Paul Balint, Christian Fourel, Julien Giraud, Josua Jacob, Thierry Lamy, Louis Latrasse, Pascal Sortais, Thomas Thuillier (LPSC, Grenoble), Cecile Daversin, François Debray, Christophe Trophime, Stéphane Veys (GHMFL, Grenoble), Ivan Izotov, Vadim Skalyga, Vladimir Zorin (IAP/RAS, Nizhny Novgorod)

LPSC and LNCMI (Laboratoire National des Champs Magnétiques Intenses) of Grenoble have developed the first and unique magnetic confinement structure in the world that allows a closed 60 GHz ECR zone, using high field magnet technologies. The magnetic structure has been validated for 28 GHz resonance and a closed 1 T iso-B surface was measured. Calculated and measured field maps were carefully compared in order to determine an operation range for 28 GHz plasma tests. A whole test bench, including high pressure water for helix cooling, intense currents (up to 15 kA) for helix powering and a beam line with mass separation is under construction at LNCMI. This contribution presents the status of the experiment, hopefully including the results of the first beam tests scheduled in September. The 350 kW - 60 GHz gyrotron has been built at IAP, the status of its operation will be shown.

This work has been supported by the EuroMagNET II under the EU contract number 228043 and by the European Commission Framework Programme 7 Design Study: EUROnu, Project Number 212372.

WEZ002

## Design of new 18 GHz ECR Ion Source

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**Kazutaka Ozeki, Yoshihide Higurashi, Takahide Nakagawa, Jun-ichi Ohnishi**  
(RIKEN Nishina Center, Wako)

In RIKEN RIBF, we plan to install a new 18 GHz ECR ion source, which supply the intense beam of highly charged heavy ion beam into the linear accelerator RILAC. By equipping two ion sources, it is expected to be able to develop new beams while we produce the beam for the experiment of RIBF. Based on the structure of 18 GHz ECR ion source which have been developed in RIKEN, this ion source has additional features as follows:

- 1) Owing to three solenoid coils,  $B_{\text{ext}}$  can be adjusted while  $B_{\text{min}}$  is fixed to an optimum value.
- 2) We adopt the variable frequency (17.2-18.4 GHz) RF power source. Therefore, further enhancement of the beam intensity is expected because the frequency band suited to a size of plasma chamber is selectable,
- 3) In order to simplify the maintenance work, we improved a structure of the chamber.

In this contribution, we report the design of new ion source in detail.

WEZ003

## Recent Results of PHOENIX V2 and New Prospects with PHOENIX V3

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**Thomas Thuillier,** Julien Angot, Thierry Lamy (LPSC, Grenoble), C. Barue, Christophe Canet, Michel Dupuis, Pascal Jardin, P. Leherissier, Frederic Lemagnen, Laurent Maunoury, Benoit Osmond (GANIL, Caen), Christophe Peaucelle (IN2P3 IPNL, Villeurbanne)

The 18 GHz PHOENIX V2 ECRIS is running since 2010 on the heavy ions low energy beam transport line (LEBT) of SPIRAL2 installed at LPSC Grenoble. PHOENIX V2 will be the starting ion source of SPIRAL 2 at GANIL. The status and future developments of this source are presented in this paper. Recent studies with Oxygen and Argon beams at 60 kV have demonstrated reliable operation at 1.3 emA of  $O^{6+}$  and 200 eμA of  $Ar^{12+}$ . Metallic ion beam production has been studied with the Large Capacity Oven developed by GANIL and 20 eμA of  $Ni^{19+}$  have been obtained. In order to improve further the beam intensities for Spiral2, an economical upgrade of the source named PHOENIX V3 has been recently decided by the project management. The goal is to double the plasma chamber volume from 0.6 to 1.2 liter by increasing the chamber wall radius, keeping the whole magnetic confinement intensity unchanged. The PHOENIX V3 magnetic design will be presented along with a status of the project.

This work is partially funded by the European Commission under the 7th Framework Programme Grant Agreement 283745 (CRISP)

WEPP01

## UV Spectral Emission Evolution during Breakdown in a 2.45 GHz ECR Hydrogen Plasma

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**Oswaldo Daniel Cortazar**, Ana Megía-Macías, Álvaro Vizcaíno-de-Julián (ESS Bilbao, LEIOA), Jani Komppula, Olli Tarvainen (JYFL, Jyväskylä)

Temporal evolution of Ly-alpha and Ly-band emissions during breakdown in a 2.45 GHz ECR plasma generator are reported. A vacuum VUV spectrometer aligned with the axis of the plasma generator and a Langmuir probe reaching into the center of plasma chamber are used to record time resolved signals with 1  $\mu$ s resolution. Transient peaks of Ly-alpha and Ly-band, simultaneously with electron temperature are observed in the very beginning of breakdown. Results for different incoming powers and magnetic field profiles suggest that such behavior is related to the nature of microwave-plasma coupling and damping of electric field with proceeding ionization. Following the ignition transient the electron temperature and density reach the equilibrium in less than 50  $\mu$ s. On the other hand, the light emission intensity of Lyman-band decreases and Lyman-alpha increases gradually, reaching steady-state in about 500  $\mu$ s. Comparison to the data from pulsed ECR ion sources, where species fraction time evolution of extracted beams have been measured, shows that observed saturation time of molecular and atomic emission is in good agreement with the saturation of extracted species fraction.

## WEPP02

### Relationship of Performance and RF Resonance Modes

**Toshiyuki Hattori**, Atsushi Kitagawa, Masayuki Muramatsu (NIRS, Chiba-shi),  
Noriyosu Hayashizaki (RLNR, Tokyo)

The performance of Electron Cyclotron Resonance (ECR) ion source depends on the operation frequency, the magnetic mirror field, the multipole field, the mirror ratio, the ECR zone and others. We studied the relationship of performance and operation frequency in ECR ion source (HiECR-3). The performance (beam intensity of  $\text{Ar}^{9+}$  ion) was measured according to change of frequency from 9.7 to 11.7 GHz in fixed magnetic field of HiECR ion source. We measured resonant frequencies of plasma chamber of HiECR ion source in condition of no plasma (current of mirror coils is zero). The data of intensity of  $\text{Ar}^{9+}$  related to measured resonant frequencies. Their resonant modes were checked with a 3D electromagnetic simulator (High Frequency Structure Simulator). As a result, it became clear that the performance of the ion source depends on electric-field distribution of the RF resonant mode.

WEPP03

## Plasma Instability in the Afterglow of ECR Discharge Sustained in a Mirror Trap

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Ivan Izotov, Dmitriy Mansfeld, Vadim Skalyga, Vladimir Zorin (IAP/RAS, Nizhny Novgorod), Tuomas Grahn, Taneli Kalvas, Hannu Koivisto, Jani Komppula, Pauli Peura, Olli Tarvainen, Ville Toivanen (JYFL, Jyvaskyla)

A number of studies have been devoted to the investigations of plasma decay in ECR heated discharges confined in a mirror magnetic trap. The motivation of this work is to study plasma instabilities causing perturbations of ion current during the plasma decay. Present work is devoted to time-resolved diagnostics of non-linear effects observed during the afterglow plasma decay of an 14 GHz Electron Cyclotron Resonance Ion Source (ECRIS) at JYFL operated in pulsed mode. Plasma instabilities causing perturbations of extracted ion current during the decay were observed and studied. It is shown that these perturbations are associated with precipitation of high energy electrons along the magnetic field lines and strong bursts of bremsstrahlung emission. The effect of ion source settings on the onset of the observed instabilities was investigated. Based on the experimental data and estimated plasma properties it is assumed that the instabilities are of cyclotron type. The conclusion is supported by a comparison to other type of plasma devices (SMIS 37, IAP RAS) exhibiting similar characteristics but operating in a different plasma confinement regime.

Work was performed in frame of realization of federal targeted program "Scientific and pedagogical labor force for an innovative Russia" for 2009-2013 yy.



WEPP04

## Geant4 Simulation of the X-ray Shielding for a High Performance ECR Ion Source

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**Byoung Chul Kim**, Eun-San Kim (IBS, Daejeon), Seyong Choi, Byoung Seob Lee, Jin Yong Park, Mi-Sook Won, Jang-Hee Yoon (Korea Basic Science Institute, Busan), J.-K. Ahn (Pusan National University, Pusan)

A third generation ECR (Electron Cyclotron Resonance) ion source produces large amounts of X-rays in the plasma chamber. The X-rays are partly absorbed by cold masses of the superconducting magnets and the absorbed energy will be an extra heat load to the cryostat. The X-ray shielding, therefore, is one of the key design issue for the high performance ECR ion source. Tantalum is usually used for the X-ray sheilding. We measured X-rays on the 10 GHz Nanogan ECR ion source to check the shielding effect of the tantalum. Geant4 simulation was carried out side by side to compare with the experimental results. Furthermore, X-rays shielding simulation for the high performance ECR ion source was done by using Geant4 and the results are presented.

WEPP05

## Status of the 18 GHz Superconducting ECRIS Construction at NFRI

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Hyun-Jong You, Soouk Jang, Yong-Ho Jung, Tae-Hyop Lho, Suk-Jae Yoo  
(NFRI, Daejeon)

In order to study the future application of highly charged ions and HCI-generated photons in areas of material interaction and/or diagnostic imaging, a new superconducting 18 GHz electron cyclotron resonance ion source (ECRIS) is being developed at National Fusion Research Institute (NFRI) in Korea. The designed NFRI-ECRIS features a high-B mode magnetic structure, two-frequency heating (18+14 GHz), higher cooling capacity of plasma chamber, movable low-emittance extraction system, and capability to generate at the same time diverse ion elements from gas to metal so that it is highly oriented to the generation of of intense HCIs and HCI-generated photons. In this presentation we describe the status of the source development including a superconducting and a permanent magnet fabrications, a plasma chamber, sputtering/oven systems for metal ion production, and a movable extraction-einzel lens system. Also we briefly summarize the near future plan to meet the source requirements for HIPAL (Highly-charged Ion Plasma Application Laboratory) application.

WEPP06

## Energy Dispersive X-ray Spectroscopy for ECR Plasma Diagnostics

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**Martin Kreller** (DREEBIT GmbH, Dresden), **Günter Zschornack** (Technische Universität Dresden, Dresden)

To understand the principal properties of anisotropic hot low-pressure plasmas in electron cyclotron resonance (ECR) ion sources the electron energy distribution needs to be investigated. This can be done by means of spectroscopy on the X-ray continuum emitted from ECR plasmas. We have measured electron-ion bremsstrahlung spectra of the 14 GHz ECR ion source of the Dresden University of Technology (TUD). To determine the electron energy distribution, the spectra were deconvolved with the help of known electron bremsstrahlung cross sections. Therefore, an integration method previously described in [1] was used. Further on, the X-ray continuum produced by Boltzmann distributed electron populations were calculated and fitted to measured spectra using the mean electron temperature as a free parameter. The resulting electron energy distributions are compared and discussed in dependence on the microwave power inserted into the ECR plasma.

[1] Friedlein, R; Kuchler, D; Zippe, C; Zschornack, G; Tyrroff, H; Energie dispersive X-ray spectroscopy for ECR plasma diagnostics. In: Hyperfine Interactions V99 p225-243 (1996)

WEPP08

## Emittance Measurements for RIKEN 28 GHz SC-ECRIS

**Kazutaka Ozeki**, Yoshihide Higurashi, Takahide Nakagawa, Jun-ichi Ohnishi  
(RIKEN Nishina Center, Wako)

In order to investigate the ion optical parameters of the beam line of RIKEN 28 GHz SC-ECR ion source into the new heavy ion linac (RILAC II), we measured the emittance of the heavy ion beams from RIKEN 28 GHz SC-ECR ion source. In the test experiments, we observed that the emittance of the  $U^{35+}$  beam was  $\sim 100 \pi \cdot \text{mm} \cdot \text{mrad}$  (4 rms emittance), which is smaller than the acceptance of the accelerator ( $\sim 160 \pi \cdot \text{mm} \cdot \text{mrad}$ ). The emittance with 28 GHz was almost same as that with 18 GHz and independent on the injected RF power (1~2 kW). The size of emittance increased with decreasing the charge state. We also measured the emittance of U and oxygen ions under the same condition. In this experiment we observed that the emittance of oxygen ions was always larger than the U ion beam for same  $M/q$ . In this contribution, we report the experimental results for emittance measurement of highly charged U, Xe and O ions from RIKEN 28 GHz SC-ECR ion source in detail.

WEPP09

## **Emittance Measurements for the Intense Heavy Ions Beams Formed by the Gasdynamic ECR Multicharged Ion Source at 37.5 GHz**

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**Alexander Sidorov**, Ivan Izotov, Sergey Razin, Vadim Skalyga, Vladimir Zorin  
(IAP/RAS, Nizhny Novgorod)

This work was aimed at the measurement of the emittance of the short-pulse (less than 100  $\mu\text{s}$ ), high current (80-100 mA) ion beams of heavy gases (nitrogen, argon), formed from the dense plasma of the ECR source of multicharged ions (MCI) with a quasi-gasdynamic confinement in a magnetic trap with a simple mirror configuration. The discharge was created by the radiation of the powerful (90 kW) pulsed gyrotron with a frequency of 37.5 GHz. The value of the ion beam normalized emittance was about of  $1\pi$  mm mrad. Based on a comparison of these results with those obtained in a cusp type magnetic trap, it is concluded that there is no influence of the structure of the magnetic field lines on the value of the emittance in terms of the gasdynamic ECR MCI source.

This work was partially performed in the framework of the Federal Targeted Program 'Scientific and Educational Personnel of the Innovative Russia' for 2009-2013.

WEPP11

## Study of Extraction and Transport for 18 GHz SC-ECRIS at RCNP

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Tetsuhiko Yorita, Mitsuhiro Fukuda, Kichiji Hatanaka, Mitsuru Kibayashi, Shunpei Morinobu, Atsushi Tamii (RCNP, Osaka)

An 18 GHz superconducting ECRIS has also been installed to increase beam currents and to extend the variety of ions, especially for highly charged heavy ions which can be accelerated by RCNP cyclotrons. The mirror magnetic field is produced with four liquid-helium-free superconducting coils and the permanent magnet hexapole is of Halbach type with 24 pieces of NEOMAX-44H material. The production development of several ions like B, O, N, Ne, Ar, Ni, Kr and Xe has been performed. Further study for its beam extraction and transport have been done in order to increase the beam injected to cyclotron. The parameters of extraction systems and electrostatic lens are optimized taking account with magnetic field leakage from AVF Cyclotron. Emittance study also has been done to see the quality of injection beam. For that purpose two types of emittance monitor have been developed. One is using three wire profile monitor and another has BPM with rotating wire for quick measurement. The details of these developments will be presented.

WEPP12

## **Magnetic Field Measurement of the Permanent Hexapole Magnet for an 18 GHz ECRIS at NFRI**

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**Soouk Jang,** Yong-Ho Jung, Tae-Hyop Lho, Suk-Jae Yoo, Hyun-Jong You  
(NFRI, Daejeon)

A permanent hexapole magnet is newly developed for an 18 GHz Electron Cyclotron Resonance Ion Source (ECRIS) at National Fusion Research Institute. The permanent magnet consists of 36 pieces of permanent magnets for hexapolar field. In order to overcome all possible irreversible losses by strong local demagnetizing field, the hexapole was made of 4 different grades of magnets and divided to 6 elementary regions. We have performed the magnetic field measurement as a function of  $z$  (-220 to 220 mm),  $r$  (0 to 41 mm) and  $\phi$  (0 to 360 degree). The resultant hexapolar field is given 1.3 T on the plasma chamber wall. In this contribution, we will present the more detailed design and properties of the hexapole magnet.

WEPP13

## Update of the LECR4-Dragon Ion Source

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**Wang Lu, Baohua Ma, Liangting Sun, Hui Wang, Daniel Xie, Xuezheng Zhang, Hongwei Zhao (IMP, Lanzhou), Lin Ruan, Bin Xiong (IEE, Beijing)**

A new room temperature ECR ion source, LECR4-DRAGON to operate at 18 GHz, is under development for the SSC-LINAC project at IMP. In comparison to other room temperature ECRISs, one unique feature of LECR4-DRAGON is that its plasma chamber is of ID 126 mm that is the biggest chamber for a room temperature ECRIS and the same as the superconducting ECR ion source SECRAL. Because the project funding requests testing a different magnet cooling scheme, solid quadrupole copper coils cooled by medium evaporation at about 50°C are to be used to produce a maximum axial magnetic field of about 2.5 T at injection and 1.4 T at the extraction, which are similar to SECRAL operating at 18 GHz. Furthermore, a large bore non-Halbach permanent sextupole with staggered structure has been under fabrication which can produce a radial magnetic field reaching 1.5 T at the plasma chamber wall for operation at 18 GHz. The progress updates and discussions of this new ion source will be presented in this paper.



WEPP14

## **An Advanced Injection System of Light Ions (AISLI) for Dielectric Wall Accelerator**

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**Shi Xiang Peng, Jia Chen, Jia-er Chen, Zhiyu Guo, Pengnan Lu, Haitao Ren, Jie Zhao (PKU/IHIP, Beijing)**

The dielectric wall accelerator (DWA) is a kind of acceleration system that has the ability to accelerate any charge to mass ratio particle with high electric field gradients up to 400 MV/m and very compact dimension, for example  $d$  30 mm x 50 mm. To demonstrate the high gradient tiny acceleration system, a comparable 50 mA/40 keV pulsed H<sup>+</sup> converge beam injector is required. Based on the experimental results obtained on the test bench, a six electrodes injector was developed at Peking University (PKU). In this paper we will describe the preliminary experimental results as well as the details of the new compact injector which named as An Advanced Injector System of Light Ions (AISLI).

WEPP15

## Metal Ion Beam Production with Improved Evaporation Ovens

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**Klaus Tinschert, Ralf Lang, Jan Maeder, Fabio Maimone, Jon Rossbach**  
(GSI, Darmstadt)

Most of the ion beams delivered by the ECR ion sources at the GSI accelerator facilities are produced from materials in the solid state, which must be transformed into the gaseous state to feed the plasma. The well established method of thermal evaporation has been used by means of two types of resistively heated ovens for metals and solid compounds. The main goal of development is to improve their versatility in terms of lifetime, durability, efficiency, and extended temperature range. Recent investigations and developments include the use of alternative materials for oven components. The main focus has been on the further development of the high temperature oven. A modular construction with improved mechanical dimensional accuracy for more precise and easier mounting has been established. Its optimization for stable long time operation has been continued leading to a lifetime of 6 days for evaporation of Ti at 1750°C. Furthermore the temperature limit could be extended to 2300°C. In addition to the improvements in evaporation technology the technique of microwave frequency tuning could be successfully applied for metal ion operation leading to enhanced ion beam intensities.

WEPP16

## Experimental Studies on the ALISES Ion Source at CEA Saclay

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**Olivier Tuske**, Olivier Delferriere, Yannick Gauthier, Raphael Gobin, Francis Harrault, Jean-Luc Jannin (CEA/DSM/IRFU, ), Sébastien Nyckees (CEA/IRFU, Gif-sur-Yvette)

The ALISES ion source was originally designed to reduce beam emittance at RFQ entrance by shortened the length of the LEBT. A wide opened magnetic coil at ground potential produces the fringe field needed for the ECR heating at 2.45 GHz frequency. The first part describes the commissioning of the source: Penning discharges inside the accelerating column make the high voltage power supply collapse. Experimental tests with kapton films while discharges occur, and simulations with OPERA-3D code have shown great similarities to detect the location of those discharges and allow us to make the ion source work. The second part of this paper will present the result of low intensity light ion beam production versus the plasma chamber length and radius. Those very preliminary tests give us indications to reduce the ion source dimensions.

WEPP17

## **A Multi-Sample Changer Coupled to an ECR Source for AMS Experiments**

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**Richard Vondrasek, Chithra Nair, Tala Palchan, Richard Claude Pardo, Robert Scott (ANL, Argonne)**

A project using Accelerator Mass Spectrometry (AMS) at the ATLAS facility to measure neutron capture rates on a wide range of actinides in a reactor environment is underway. This project will require the measurement of a large number of samples previously irradiated in the Advanced Test Reactor at Idaho National Laboratory. The AMS technique at ATLAS is based on production of highly-charged positive ions in an electron cyclotron resonance ion source (ECRIS) followed by acceleration in the ATLAS linac. The sample material is introduced into the plasma via laser ablation. This should limit the dependency of material feed rates upon the source material composition as well as minimize cross-talk between samples. A new multi-sample changer has been constructed allowing rapid changes between samples. The sample changer has 20 positions and is capable of moving from one sample to the next in one minute. Details of the sample changer design and operation will be presented.

This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

WEPP16

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WEPP17

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This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

WEPP18

## **CARIBU ECR Charge Breeder Background Studies**

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**Richard Claude Pardo, Matthew Hendricks, Holly Lighthall, Guy Savard, Robert Scott, Richard Vondrasek (ANL, Argonne)**

We have undertaken studies to identify the stable beam backgrounds that cause 'contamination' of the ECR ion source charge-bred radioactive beams from CARIBU. Charge breeding of the radioactive species is necessary step prior to the acceleration of the beams in the ATLAS linac. Ion species whose  $(m/q)$  ratio is within 0.2% of the desired radioactive species  $(m/q)$  ratio cannot be discriminated against by the present accelerator configuration. Although there are many  $(m/q)$  instances in which an intense stable beam is sufficiently degenerate with the species of interest that no discrimination is possible, we also find many cases in which the stable beam background is in an acceptable range of intensity and can be dealt with by the experiment detection system. Examples of such situations will be presented as well as some discussion of ideas for improving the discrimination against stable beam backgrounds.

This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357.

THX001

## Optimization of the New SC Magnetic Structure with Hybrid Magnet

---

Daniel Xie, Wang Lu, Lizhen Ma, Liangting Sun, Xuezhen Zhang,  
Hongwei Zhao (IMP, Lanzhou)

In the development of the next generation ECRISs, so far either a set of full NbTi or full Nb<sub>3</sub>Sn magnets has been proposed to construct the magnet system. However, the single set of magnets may not be the optimum in terms of the field strength and configuration. An optimization of the new SC magnetic structure with a set of hybrid magnets (NbTi and Nb<sub>3</sub>Sn) is being investigated. With the hybrid magnet the optimized new magnetic system is capable of producing field maxima of 9.0 T on axis and 4.0 T at the plasma wall, which are 30 and 10% higher than the previously proposed magnetic structure to be built with a set of full NbTi magnets. In addition, the axial length of the optimized magnetic structure has been slightly shrunk resulting in a more compact system. This new magnetic field profile is high enough for operation frequency up to 56 GHz. The design features and the preliminary force/stress analyses of the optimized new SC magnetic structure will be presented and discussed.



THX002

## Current Developments of the VENUS Ion Source in Research and Operations

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Janilee Yvette Benitez, Ken Yoshiki Franzen, Claude M Lyneis, Larry Phair, Markus Michael Strohmeier (LBNL, Berkeley, California), Guillaume Machicoane (FRIB, East Lansing, Michigan), Liangting Sun (IMP, Lanzhou)

The VENUS ion source functions as a research and development tool in the ECR community as well as an injector for LBNL's 88-Inch cyclotron. In order to meet the needs of both the ECR community and users at the 88-Inch cyclotron, technology such as ovens and a sputter probe have been developed for introducing metals into the plasma. Using a modified high temperature oven, VENUS has produced 450 eμA of  $^{238}\text{U}^{33+}$  and 400 eμA of  $^{238}\text{U}^{34+}$ , twice the required Uranium beam current needed for FRIB. In addition, after upgrading its high voltage capabilities VENUS produced 11eμA of  $4\text{He}^{2+}$ , a capability that remains unparalleled by other ECR ion sources. In addition to its recent record high intensities VENUS is also being developed to deliver low intensity, ultra high charge state ions for the cocktails beams, where many species are produced simultaneously for use by the BASE Facility.  $^{124}\text{Xe}^{43+}$  is now in regular production for the 16 MeV/u cocktail, and development of  $^{209}\text{Bi}^{56+}$  for the 10 MeV/u cocktail is in progress and has been accelerated through the 88-Inch cyclotron. This paper presents the latest work towards integrating the VENUS ion source into our research and operational goals.

THX003

## Recent RIKEN 28 GHz SC-ECRIS Results

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**Yoshihide Higurashi**, Masaki Fujimaki, H. Haba, Osamu Kamigaito, Masanori Kidera, Misaki Komiyama, Takahide Nakagawa, Jun-ichi Ohnishi, Kazutaka Ozeki (RIKEN Nishina Center, Wako), Toshimitu Aihara, Masashi Tamura, Akito Uchiyama (SHI Accelerator Service Ltd., Tokyo)

For increasing the beam intensity of highly charged heavy ions at RIKEN RIBF, we constructed new SC-ECR ion source. In the spring of 2011, we injected 28GHz microwave into the ion source and obtained first beam. Since then, we made several test experiments for increasing the beam intensity of highly charged Xe and U ion beam, and produced  $\sim 60 \text{ e}\mu\text{A}$  of  $\text{U}^{35+}$ ,  $\sim 90 \text{ e}\mu\text{A}$  of  $\text{U}^{33+}$  at the injected RF power of  $\sim 2 \text{ kW}$  using sputtering method. In case of  $\text{Xe}^{25+}$ ,  $250 \text{ e}\mu\text{A}$  was obtained at RF power of  $1.7 \text{ kW}$ . Using sputtering method, we produced  $\text{U}^{35+}$  ion beam longer than one month for the RIBF experiment without break. In the beginning of 2012, we installed additional GM-JT refrigerator to increase the cooling power at  $4.2 \text{ K}$ , then the total cooling power became higher than  $9 \text{ W}$ . Using it, we can use higher than  $8 \text{ W}$  of cooling power for heat load due to the absorbed X-rays. In this summer, we will install the new plasma chamber made of Al for increasing the cooling power. We will also use high temperature oven to increase the U vapor. In this contribution, we report the recent modification of the ion source and test experiments for production of U and Xe ion beam.

THX004

## SECRAL status and future challenge

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Hongwei Zhao, Wang Lu, Liangting Sun, Daniel Xie, Xuezheng Zhang  
(IMP, Lanzhou)

SECRAL, the superconducting ECR ion source at IMP, has been in routine operation for the HIRFL accelerator complex since May 2007. The total operation beam time provided by SECRAL has so far exceeded 9500 hours. In most cases SECRAL has been operating at 18 GHz for the accelerator complex, and only operating at 24 GHz for the very high charge states and very heavy ion beams such as Bi and U beams. Uranium beam was tested at 24 GHz with ion sputtering in which 160 eμA of  $^{238}\text{U}^{33+}$  was produced, and  $^{238}\text{U}^{32+}$  beam was delivered to the accelerator continuously for almost one month. Beam long-term stability and emittance at high rf power of 24 GHz were studied. The operation status and the latest performance of SECRAL ion source will be presented. A new heavy ion accelerator facility HIAF has been proposed at IMP. HIAF requests an ion source capable of producing a pulse beam of 2.0 emA of  $^{238}\text{U}^{34+}$ . A next generation superconducting ECR ion source with operating frequency up to 50-60 GHz is under consideration in which a few options for the superconducting magnet configuration are being studied. Technical challenges for the next generation ECR ion source will be reviewed.

THY001

## Operation of an ECRIS Charge State Breeder at TRIUMF

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Friedhelm Ames, Richard Baartman, Pierre Gerard Bricault, Keerthi Jayamanna, Anders Mjøs (TRIUMF, Vancouver)

After initial commissioning of the charge state breeder for radioactive ions at the TRIUMF/ISAC facility further tests on the performance of the system have been performed. One of the major problems found was the high background of stable ions from the ECR source, mainly C, N, O, Ar, Fe, Ni, C and Cr. The main source of those is the residual gas and sputtered material from the plasma chamber wall and from the surrounding electrodes. Although their intensity is small it can be orders of magnitude more than the intensity from the radioactive ions. Therefore, the original stainless steel plasma chamber of the Pantechnik PHOENIX ECR source has been exchanged to aluminium with an ultra pure aluminium coating, all electrodes for injection and extraction of the ions have been replaced with aluminium and the iron joke at the extraction side, which is part of the vacuum system in the PHOENIX source has been coated as well. This combined effect has reduced the amount of background ions substantially. Detailed results on the performance of the source after those changes will be presented.

THY002

## LPSC PHOENIX ECR Charge Breeder Beam Optics and Efficiencies

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**Julien Angot**, Thierry Lamy, Mélanie Marie-Jeanne, Pascal Sortais, Thomas Thuillier (LPSC, Grenoble)

The PHOENIX ECR charge breeder characteristics (efficiency and charge breeding time) were measured at CERN-ISOLDE and LPSC, they were considered as sufficient to allow its setup on various facilities (TRIUMF-Canada/GANIL-SPIRAL2-France/SPIRAL1). The developments performed at the Argonne National Laboratory (USA) have shown that the ECR charge breeder efficiencies could be much higher than the ones obtained with PHOENIX, without major differences between the two devices. We have tried to study the possible reasons of such different results in order to improve the PHOENIX charge breeder characteristics. The transmission value of the  $n^+$  beam line has been measured to be as low as 30%. Emittances of the total beam extracted from the source and of some analyzed beams (after the magnetic spectrometer) have been measured and will be presented. Simulations have shown a too low vertical acceptance at the center of the dipole. Simulations and experimental results will be presented to show how an additional Einzel lens inserted just before the dipole have drastically improve the beam transmission. The impact of this new beam transport on efficiency results will be presented.

THY003

## Design Status of FRIB ECR Ion Sources and Low Energy Beam Transport

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**Guillaume Machicoane, Nathan Bultman, Daniela Leitner, Eduard Pozdeyev, Xing Rao (FRIB, East Lansing, Michigan), Liangting Sun (IMP, Lanzhou), Janilee Yvette Benitez, Claude M Lyneis (LBNL, Berkeley, California)**

The Facility for Rare Isotope Beams at Michigan State University is currently being designed and will provide intense beams of rare isotopes for research in nuclear physics, nuclear astrophysics and study of fundamental interactions. The FRIB driver linac will accelerate all stable isotopes from Oxygen to Uranium to energies beyond 200 MeV/u at beam powers up to 400 kW. In the case of Uranium about 13.3  $\mu\text{A}$  of  $\text{U}^{33+}$  are required from the ion source to reach the maximum beam power on the target. Such current is at the limit of what an ECR ion source can produce and led us to design the FRIB driver linac to accelerate concurrently two charges. The ECR ion source for FRIB will be based on the VENUS ion source developed at Lawrence Berkeley National Laboratory (LBNL). Recent beam measurements done with VENUS have demonstrated that the ion source can actually produce close to 13 $\mu\text{A}$  of  $\text{U}^{33+}$  and therefore could possibly meet the current required for FRIB in one charge state. This paper reviews the status of the FRIB ECR ion source and the modifications that have been made to the VENUS ion source design. The Low energy beam line transport (LEBT) will also be presented and discussed.

Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661

THY004

## Performance of the ANL ECR Charge Breeder with Low Mass Beams

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Richard Vondrasek, Richard Claude Pardo, Robert Scott (ANL, Argonne),  
Pierre Delahaye, Laurent Maunoury (GANIL, Caen)

The Californium Rare Ion Breeder Upgrade (CARIBU) of the ATLAS superconducting linac facility aims at providing low-energy and reaccelerated neutron-rich radioactive beams to address key nuclear physics and astrophysics questions. These beams are obtained from fission fragments of a Cf-252 source, thermalized and collected into a low-energy particle beam by a helium gas catcher, mass analyzed by an isobar separator, and charge bred with an ECR ion source for acceleration in ATLAS. The charge breeding program had focused on optimizing beams in the mid-mass range, achieving high charge breeding efficiencies of both gaseous and solid species including 14.7% for the radioactive species  $^{143}\text{Ba}^{27+}$ . In an effort to better understand the charge breeding mechanism, we recently focused on the low-mass species sodium and potassium which up to present have been difficult to charge breed efficiently. Charge breeding efficiencies of 10.1% for  $^{23}\text{Na}^{7+}$  and 17.9% for  $^{39}\text{K}^{10+}$  were obtained injecting stable  $\text{Na}^+$  and  $\text{K}^+$  beams from a surface ionization source. Details of these studies will be presented as well as simulations detailing the injection of the low charge state beams into the charge breeder.

This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

FRXA01

## High Intensity Beam Production at CEA/Saclay for the IFMIF Project

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**Raphael Gobin,** Guillaume Adroit, Daniel Bogard, Nicolas Chauvin, Olivier Delferriere, Yannick Gauthier, Patrick Girardot, Francis Harrault, Jean-Luc Jannin, Denis Loiseau, Pierre Mattei, Arnaud Roger, Franck Senee, Olivier Tuske (CEA/DSM/IRFU, )

At CEA/Saclay, IRFU institute is in charge of the design, construction and characterization of the 140 mA continuous deuteron Injector for the IFMIF project. This injector includes the source and the low energy beam line (LEBT) with its own diagnostics. The Electron Cyclotron Resonance (ECR) ion source operates at 2.45 GHz and the 2 m long LEBT is based on 2 solenoids. Krypton gas injection in the beam line is foreseen in order to reach a high level of space charge compensation for the beam matching at the RFQ entrance. During the last months hydrogen beam has been produced in pulsed and continuous mode and the beam diagnostics have been installed and commissioned. Recently a 125 mA-100 keV pulsed deuteron beam has been produced with a 1% duty cycle. In this article, the high intensity proton and deuteron beam characterization will be presented.



FRXA02

## All Permanent Magnet ECR Ion Source Development and Operation Status at IMP

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**Liangting Sun,** Yun Cao, Jiaqing Li, Jinyu Li, Baohua Ma, Hui Wang, Jia Wen Xia, Daniel Xie, Wenhui Zhang, Xuezheng Zhang, Hongwei Zhao (IMP, Lanzhou)

All permanent magnet ECR ion sources have many advantages over traditional ECR ion sources composed of several axial room temperature solenoids and one permanent magnet hexapole magnet, which make them the first choice for many heavy ion facilities and platforms. At IMP, three types of all permanent magnet ECR ion sources have been built for different applications, i.e. the very compact ECR ion source LAPECR1 for intense mono or multi charge state ion beam production, the LAPECR2 ion source installed on the 320 kV high voltage multidisciplinary platform, and the LAPECR3 ion source dedicated to  $C^{5+}$  beam production for the cancer therapy facility. In this paper, after a general discussion of the ion sources' design, the applications and the operation status of the IMP all permanent magnet ECR ion sources will be presented.

FRXA03

## **Laser Ablation of Actinides into an Electron Cyclotron Resonance Ion Sources for Accelerator Mass Spectroscopy**

Tala Palchan, Filip G. Kondev, Sergei A. Kondrashev, Chithra Nair, Richard Claude Pardo, Robert Scott, Richard Vondrasek (ANL, Argonne), Jeffrey Berg, Thomas Maddock, Giuseppe Palmotti, Gilles Youinou (INL, Idaho Falls, Idaho), Massimo Salvatores (INL, Idaho Falls, Idaho; CEA Cadarache, Saint Paul Lez Durance), George Imel (ISU, Pocatello, Idaho), Michael Paul (The Hebrew University of Jerusalem, Jerusalem), William Bauder, Philippe Collon (University of Notre Dame, Indiana)

A project using accelerator mass spectrometry (AMS) is underway at the ATLAS facility to measure the atom densities of transmutation products present in samples irradiated in the Advanced Test Reactor at INL. These atom densities will be used to infer effective actinide neutron capture cross-sections ranging from Thorium to Californium isotopes in different neutron spectra relevant to advanced fuel cycles. This project will require the measurement of many samples with high precision and accuracy. The AMS technique at ATLAS is based on production of highly-charged positive ions in an ECRIS followed by injection into a linear accelerator. We use a picosecond laser to ablate the actinide material into the ion source. We expect that the laser ablation technique will have higher efficiency and lower chamber contamination than sputtering or oven evaporation thus reducing 'cross talk' between samples. The results of off-line ablation tests and first results of an accelerate beam generated by the laser coupled to the ECR will be discussed as well as the overall project schedule.

This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357.

FRYA01

## ECRISs at GANIL Today and Tomorrow

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**Pascal Jardin**, Olivier Bajeat, C. Barue, Christophe Canet, Pierre Delahaye, Mickael Dubois, Michel Dupuis, Jean Luc Flambard, Romain Frigot, Christian Leboucher, P. Leherissier, Frederic Lemagnen, Laurent Maunoury, Benoit Osmond, Emil Traykov (GANIL, Caen), Olivier Tuske (CEA/DSM/IRFU, ), Christophe Peaucelle (IN2P3 IPNL, Villeurbanne), Thomas Thuillier (LPSC, Grenoble)

GANIL (Grand accélérateur National d'Ions Lourds) uses ECRIS for producing stable and radioactive ions since more than 20 years. 2 ECR4 type IS deliver intense multi-charged stable ion beams of gaseous and metallic elements to cyclotrons for post acceleration to energies up to 100 A·MeV. A full permanent magnet ECRIS is also used for producing multi-charged radioactive ion beams in the frame of SPIRAL 1 (Système de Production d'Ions radioactifs Accélérés en Ligne, part 1). For atomic physic experiment, a high performance ECRIS named GTS developed at CENG/ Grenoble (France) is currently used to deliver high intensity, high charge state and low energy ion beams. To extend the range of radioactive ion beams available at GANIL, two ISOL (Isotope Separator On Line) projects are underway (SPIRAL2 and SPIRAL1 upgrade). In the frame of these projects, radiation hard singly-charged ECRIS,  $Q/A=1/3$  ECRIS, 2.45 GHz deuteron ECRIS and permanent magnet TISS (Target Ion Source System) using an ECRIS are in development in parallel. A review of the main uses, current developments and performances obtained or expected with ECRISs at GANIL will be presented.

FRYA02

## Status of ECR Ion Sources for Carbon-ion Radiotherapy in Japan

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**Atsushi Kitagawa**, Masayuki Muramatsu (NIRS, Chiba-shi), Noriyuki Sasaki, Wataru Takasugi (AEC, Chiba), Eri Takeshita, Satoru Yamada (Gunma University, Maebashi-Gunma), Arne G. Drentje (KVI, Groningen), Takashi Fujita (National Institute of Radiological Sciences, Chiba), Mitsutaka Kanazawa (SAGA HIMAT, Saga)

Heavy-ion radiotherapy is successfully carried out at the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS) since 1994. Now three facilities are in operation and two are under construction in Japan. Over 8000 cancer patients have already been treated. 140-400 MeV/u carbon beams were selected for the first clinical trials at HIMAC because carbon is one of the best candidates which gives good localized biological dose distribution for the typical conditions, a depth of 10 - 25 cm and a thickness of several cm. Based on the clinical results, all the patients have been treated by carbon beams at present. The ion source needs to realize a stable carbon beam with the same conditions for daily operation. Since operators are usually not specialists of the ion source, the source should not require complicated manual tuning. In addition, shorter maintenance time and cycle are better for a hospital. ECR ion sources are utilized for such requirements in each facility. We report the recent status of the ECR ion sources at heavy-ion radiotherapy facilities in Japan.

FRYA01

FRYA03

## ECRIS Related Research and Development Work at JYFL and Some Future Prospects

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Hannu Koivisto, Juha Eerik Arje, Taneli Kalvas, Jani Komppula, Risto Juhani Kronholm, Janne Laulainen, Olli Tarvainen, Ville Toivanen (JYFL, Jyvaskyla)

Since the last ECR workshop the JYFL ion source group has focused on the plasma research, work on the ion beam formation and transport and development of metal ion beams. The plasma research can be divided into plasma breakdown processes, plasma and ion beam instabilities and afterglow processes. The afterglow and instability experiments will be presented elsewhere in these proceedings [1]. In addition, studies involving in the photoelectric induced electron emission and charge exchange reactions will be briefly discussed and the experiments concerning the resonance properties of empty and plasma loaded cavity will be presented. An improvement in ion beam transport of the JYFL K130 cyclotron facility was achieved as a result of the work performed on ion beam formation. This work will be described in more detailed elsewhere in these proceedings [2]. The MIVOC method and sputtering technique were further studied in order to produce intensive titanium ion beams. As a result, an intensive  $^{50}\text{Ti}$  ion beam was successfully produced with the MIVOC method and interesting behavior regarding the sputtering was noticed.

[1] V. Skalyga et al. and O. Tarvainen et al.

[2] V. Toivanen et al.





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