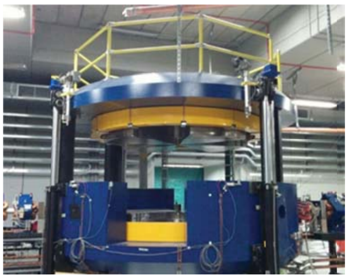

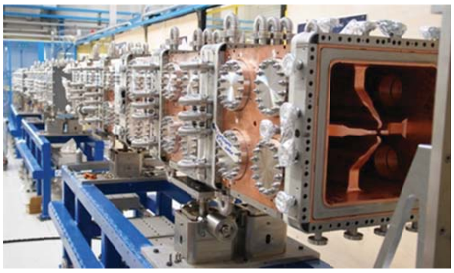

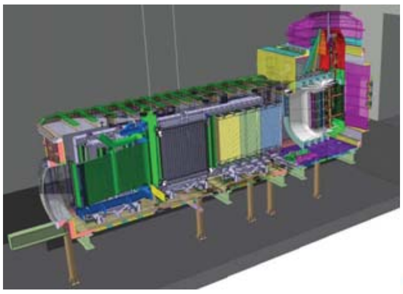

Book of Abstracts

International Workshop

IPAB2016

Intense and Powerful Accelerator Beams for industrial and energy application

INFN Laboratori Nazionali di Legnaro
"Villi" Meeting Room
March 14-15, 2016

International Scientific Committee

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SCOPE OF THE MEETING

The focus of the meeting will be on applications of high current and powerful particle accelerators and sources, with particular attention to benefit of high current sources.

Subtopics are: satellite propulsion; negative ion beams for fusion; negative and positive ions in industrial application; electron beams for seeds, food and waste processing; material resistance and tests; medical applications and treatment times. The scope of the workshop also covers: radioisotope production; accelerator and beam source technology, superconductivity, energy efficiency and recover; application of accelerator based analytical and diagnostic techniques (AMS, PIXE).

For more information, see the Conference website: http://ipab2016.lnl.infn.it/

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EuCARD² Accelerator Application Network Activity - Work Package 4

IPAB2016 (Intense and Powerful Accelerator Beams for industrial and energy application)

Monday 14 March 2016 - Wednesday 16 March 2016

INFN Laboratori Nazionali di Legnaro

Book of abstracts

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Afternoon session (Chair: V. Antoni) / 26

Discussion D2: Poster highlights; free discussion

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A space where brief oral summaries of poster may be shown, if desired, as well as other materials for discussion.

Minutes prepared by convener(s) may be posted on the website, as well as short presentations (3 slide max) received for the discussion.

Morning Session (Chair: P. Veltri) / 4

Determination of plasma parameters via optical emission spectroscopy at CERN's Linac4 H− ion source

BRIEFI, Stefan [1]; FINK, Daniel [2]; MATTEI, Stefano [2]; LETTRY, Jacques [2]; FANTZ, Ursel [3]

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At the accelerator complex of CERN an upgrade of the LHC injector chain is being implemented. This upgrade includes the installation of a linear accelerator based on negative hydrogen ions, the Linac4. The ion source of Linac4 relies on inductive RF coupling with an external coil for discharge generation (RF frequency 2 MHz, maximum RF power 100 kW). In general, the H− ions can be generated via two processes: first, the volume process, where H− is created from vibrationally excited hydrogen molecules by electron impact dissociation. For the second one, the surface process, caesium is evaporated into the source in order to establish a surface with low work function. H− is produced from hydrogen ions and atoms impinging on that surface. As caesium is very reactive, the stability of the H− production rate is an issue for using the surface process. However, the H− production is generally enhanced strongly compared to the volume process and it is accompanied by a reduction of the co-extracted electron current. In order to optimize the H− yield for both processes, a detailed knowledge of the plasma parameters and the dominant control parameters is mandatory.
Insight in the plasma parameters can be obtained via optical emission spectroscopy (OES) and the evaluation of the results with collisional radiative models. These models balance the de- and excitation processes of all relevant atomic or molecular states in the discharge. Hence, modelling the measured population densities yields plasma parameters like the electron density and temperature. For the Linac4 ion source, high resolution OES measurements of the hydrogen plasma have been carried out, considering the atomic Balmer radiation and the molecular Fulcher emission (a transition, located between 590 and 650 nm). The plasma parameters obtained from the evaluation of these measurements are presented for a variation of the gas pressure and RF power.

Morning session (Chair: A. Faus-Golfe) / 10

Compact FFAG for Radioisotope Production

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A design of a Fixed Field Alternating Gradient (FFAG) accelerator has been made for the production of radioisotopes, in particular 99m-Tc and a number of therapeutic isotopes currently in short supply. As well as fixed magnetic fields, this machine is isochronous at the level of 0.3% up to at least 28 MeV and hence able to operate in constant wave (CW) mode. Detailed tracking studies with the OPAL (Object Oriented Parallel Accelerator Library) code, including the effects of space charge, have demonstrated the ability to accelerate a beam with a current of up to 20 mA, significantly larger than achievable with any current cyclotrons. The accelerator is able to deliver beams of both protons and alpha particles. Two target options for the production of radioisotopes are being considered. The first uses a thin internal target. The huge acceptance of the accelerator allows the beam to be recirculated many times, the lost energy being restored on each cycle. In this way, the production of 99m-Tc for example, can take place at the optimum energy. The second option is to use an electrostatic deflector and septum for extraction. This will allow the clean extraction of high current beams, for example alphas for the production of therapeutic isotopes.

Afternoon session (Chair: V. Antoni) / 6

Review of LNL Accelerators for Applied Physics: AN2000, CN and related experiments

CANELLA, Stefania [1]; LA TORRE, Leonardo [1]; MARAN, Luca [2]; MUNARON, Enrico [2]

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A review of the two LNL small accelerators mainly dedicated to applied physics (AN2000 and CN) is given. Their foreseen use in the next years is then presented.
The experiments related to applied physics performed in the last 2 years at AN2000 and CN are also described, with special attention to those interesting for application of accelerator based analytical and diagnostic techniques (PIXE and others). Perspectives for LNL small accelerators in this field will be also given.

Afternoon session (Chair: M. Cavenago) / 28

Discussion D4: industrial application of intense (negative) ion source

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Conclusive discussion on applications shown at the conference.
Perspectives of ion sources for hydrogen and deuterium, and other elements (negative ion, and/or positive).
Perspective of (new) collaborations.

Minutes prepared by convener(s) may be posted on the website, as well as short presentations (3 slide max) received for the discussion.

Poster session / 17

Beam optics and magnet studies for neutralizer storage rings

CAVENAGO, Marco [1]; VELTRI, Pierluigi [1]; SARTORI, Emanuele [2]

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The design of efficient storage rings with large acceptance so that a neutralizer gas cell can be inserted requires both linear matrix formalism and full field tracking calculation. Moreover large magnet aperture must be considered.
First an unbiased search of suitable lattices is needed. Matrix formalism is simple enough to allow use of symbolic manipulation programs, with s the beam direction, x,y the transverse coordinates, and Mx, My the corresponding transport matrices: the conditions that
$|\text{trace}(Mx)| < 2$ and $|\text{trace}(My)| < 2$
can be reduced (automatically) to simple inequalities for lattice side lengths. Numerical optimizations are also discussed.
Differently from usual storage rings, primary beam consumes in few passage through neutralizer cell, so angle injection seems possible.
Field tracking simulation needs a rapid method to calculate field from pole footprints and shape, which preferably avoids the use of differential formulas. The method proposed is compared with analytic result for flat poles. After determining suitable magnet poles, full 3D magnets are designed, for verification.
Analogies with Fixed-Field Alternating Gradient (FFAG) accelerators are noted.

Poster session / 16

High current storage rings for neutral beam injectors

CAVENAGO, Marco [1]; VELTRI, Pierluigi [1]; SERIANNI, Gianluigi [2]; SARTORI, Emanuele [3]; SONATO, Piergiorgio [2]; ANTONI, Vanni [4]

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The gas neutralizer converter used to produce a neutral hydrogen (or deuterium) beam from a H- (or D-) beam has intrinsic limitation on conversion efficiency and requires a residual ion dump for H-, and produced H+. By recirculating H- into gas neutralizer N times (with N up to 4) conversion efficiency can be increased and the ion dump size is greatly reduced. In other words, the gas neutralizer becomes one element of a large acceptance H- storage ring, which is here studied both with linear theory and with numerical simulation.
Among several practical solutions, the rectangular lattice with M=2 and M=4 bending dipole seems the more convenient for an initial studies; symmetry number (number of equal section per turn) is S=2 for both lattices.
It is important to control secondary ion accumulation inside storage rings, which has beneficial effect (reduction of space charge) and unwanted effects (beam stripping in dipoles); clearing electrodes may be useful. Among advanced concepts, note first that controlling secondary plasma may also produce a plasma neutralizer, with higher efficiency. Second, adding a H+ storage ring, with a long straight section in common, is a convenient method to exploit the H+ and H- mutual neutralization, so that in principle conversion effiency may approach unity.
Application to fusion and other use of dual beam technology are also reviewed.

Morning session (Chair: A. Faus-Golfe) / 1

Particle accelerators for the production of medical radioisotopes

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Radioactive isotopes play a key role in biology to unearth fundamental cellular processes. By acting as labeling tags, gamma-emitting radionuclides are useful tools to visualize the interaction of molecular probes targeting specific biomolecules in living organisms by means of external detectors. This information is an essential component of the current paradigm of molecular imaging, a diagnostic approach aimed at elucidating the origin and intrinsic nature of diseases at the molecular level. In turn, this fundamental knowledge can be used to develop more efficient therapeutic strategies that are tailored to a single individual based on his/her chemical profile (chemotype).

A key discovery has been that there exists a subset of radioisotopes that naturally manifest favorable biological properties for diagnostic and therapeutic purposes because their associated elements either have a recognized key biological role or mimic the behavior of biologically active elements. A classical example is provided by iodine radioisotopes widely employed for imaging thyroid function and for therapy of thyroid cancer as a result of the natural involvement of iodine in thyroid metabolism. Other relevant examples are offered by rubidium-82 mimicking potassium ions for imaging cardiac function, and strontium-89 and radium-223 employed in the treatment of bone cancer as analogs of calcium ions.

Although some radioisotopes are obtained through nuclear reactions characterized by high cross sections for neutron or proton irradiation of suitable targets, some biologically relevant radionuclides are extremely difficult to obtain by conventional methods, relying on available nuclear reactors and low-energy, low-current cyclotrons, in sufficient amounts to allow their widespread medical use. These include, among others, copper, zinc, iron and manganese radioisotopes having highly interesting nuclear and biological properties suitable for both diagnosis and therapy.

This lecture will review the crucial role played by nuclear physics in developing efficient methods for the production of medical radionuclides and current challenges in achieving satisfactory yields of formation of highly interesting and potentially useful radionuclides that are still not available in sufficient amounts to the medical community.

Morning session (Chair: A. Faus-Golfe) / 20

High power-low energy accelerators for neutron production:MUNES and IFMIF-EVEDA case

FAGOTTI, Enrico [1]; PISENT, Andrea [1]; COLAUTTI, Paolo [1]

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Two high power low energy accelerators for neutron production are under construction and testing at LNL-INFN.
MUNES couples a 30 mA, 5 MeV proton beam to a Be target to generate a neutron flux of 10^14 n/s, with a spectrum centered in the 2 MeV region. This neutron flux can be moderated to generate a thermal or epithermal neutron source for different applications. Among them Boron Neutron Capture Therapy or nuclear waste characterization. The whole accelerator is produced by INFN in collaboration with local industry.
IFMIF aims to produce an intense neutron flux to test and qualify materials suitable for the construction of fusion power plants. The final project will produce a 10^14 n/(s*cm^2) neutron flux with 14.1 MeV energy. It is based on an international collaboration between F4E and JAEA. In this framework INFN is producing the high intensity RFQ that can accelerate the 125 mA deuteron beam up to 5 MeV.

Poster session / 22

New thermal neutron source at LNL

FAGOTTI, Enrico [1]; PISENT, Andrea [1]; COLAUTTI, Paolo [1]; MORO, Davide [1]; BEDOGNI, Roberto [2]; POLA, Andrea [3]; Dr. BORTOLUSSI, Silva [4]

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[4] *INFN-PV*

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In the framework of MUNES project, a new neutron source was developed at the CN electrostatic accelerator of Legnaro National Laboratories.
Neutrons are produced thruogh Be(p,n) reaction using a thin foil beryllium target brazed on a copper base. A 5 MeV, 3 microA proton beam is focalized onto the target so as to reach a 500 W/cm^2 power density on beryllium, the same as MUNES high intensity accelerator.
A heavy water-graphite moderator is used for neutrons thermalization.
Preliminary results show that a 1.2*10^6 s^-1*cm^-2 neutron density can be generated at the extraction window with a uniformity better than 1% over a 25 cm diameter circular area.
Neutron spectrum is more than 90% thermal with a very low gamma contamination.

Morning Session (Chair: P. Veltri) / 3

Powerful RF ion sources for fusion

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The neutral beam injection system for the international fusion experiment ITER is based on large and powerful RF-driven ion sources which have to deliver extracted negative hydrogen ion currents of 66 A (H^-) and 57 A (D^-) being accelerated to 870 keV and 1 MeV, respectively. The hydrogen plasma is generated in eight individual cylindrical RF-drivers for which a total RF power of up to 800 kW at a frequency of 1 MHz will be available. The plasma expands in a rectangular expansion source with a width of 0.9 m and a height of 1.9 m. The negative hydrogen ions are created by utilizing the conversion of hydrogen atoms at a surface with low work function for which caesium is evaporated into the source. Extraction takes place from 1280 apertures with a diameter of 14 mm each resulting in an extraction area of 0.2 m2. In order to prevent damages of the grid system, the co-extracted electron current has to be kept below the extracted ion current. The source must be operated at a pressure of 0.3 Pa at maximum to limit the ion losses in the accelerator. Another challenging requirement concerns the beam duration and homogeneity: beams up to 3600 s have to be achieved with deviations in the uniformity over the large beam below 10%.

The RF prototype source for ITER (1/8 scale) has been successfully developed in the last years. At the test facility BATMAN it was demonstrated that the required negative ion current density can be achieved at 0.3 Pa with an electron-to-ion ratio below for short pulses (4 s), whereas MANITU demonstrated long pulse operation up to one hour for hydrogen and deuterium but with reduced beam parameters. RADI was a size scaling experiment without extraction for the purpose to prove the modular driver concept and to illuminate homogeneously an area of half the size of the ITER source.

As the required parameters have not been achieved simultaneously in a large source, the facility ELISE has been set up as part of the R roadmap of the European ITER domestic agency F4E. ELISE is dedicated to demonstrate the required negative hydrogen densities (extracted: 329 A/m2 H^-, 286 A/m2 D^-) at an electron-to-ion ratio of less than one for a source of the same width but only half the height of the ITER source (0.9 x 1 m2). Consequently, the ELISE source is driven by four RF drivers for which a total RF power of 360 kW is available. Since the first plasma in March 2013, ELISE has made enormous progress towards the ITER parameters: first stable one hour discharges with 10 s beam pulses every 3 min (limited by the available high voltage power supply) are demonstrated in hydrogen and deuterium, however at reduced RF power only. The limiting factor in the source performance is the amount and the temporal stability of co-extracted electrons, which is in particular a challenge for deuterium. Advanced beam diagnostics reveal that the requirements in beam uniformity of these large beams (about 1x1 m2) can be met.

Afternoon session (Chair: V. Antoni) / 21

The Applications of Particle Accelerators in Europe (APAE)

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Originally developed to investigate the fundamental laws of nature, particle accelerators accelerate charged particles to incredibly high speeds before using them for a variety of purposes. Today, accelerators are far more than a tool for fundamental research and their significant role in industry and society means that they have a very important, but often unseen, impact on our everyday lives.
Over 30,000 particle accelerators are in use all over the world. In fact, until recently, most people had one in their sitting room. They allow beams of particles to be produced and used for a range of applications in a number of different areas, including health, industry, energy production, security and environment.
The key questions when we start to think about the project: ”The Applications of Particle Accelerators in Europe (APAE)” are: Why we need the accelerators? Where are they? What will be the impact of particle accelerators on tomorrow’s society? What are the needs for the future? etc.
The aim of the project is to create a European document equivalent of the "Accelerators for America's Future", but focused on applications of interest in Europe and for which technology developed for research can have an impact. The document it is intended for policy makers, as a result, it will be in two parts: an executive summary, focussing on the main issues for each country and in the correct language and a supporting document in English. WP4 of EUCARD2 is organizing the project.

Afternoon session (Chair: V. Antoni) / 30

Welcome and introduction to LNL (G. Fiorentini, LNL Director)

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Afternoon session (Chair: V. Antoni) / 7

Progresses about Microwave Discharge Ion Sources for high intensity protons and light ions’ beams production at INFN-LNS

GAMMINO, Santo [1]; CELONA, Luigi Giuseppe [1]; CASTRO, Giuseppe [1]; LEONARDI, Ornella [1]; MASCALI, David [1]; NERI, Lorenzo [1]; SORBELLO, Gino [2]; TORRISI, Giuseppe [1]

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The diffusion of large-scale facilities based on high intensity linear accelerators for both fundamental or applied research has triggered the development of multi-mA proton/light ions sources. At INFN-LNS a great deal of work has been done on modelling, design and construction of several Microwave Discharge Ion Sources, according to the demands coming from different projects like TRASCO, ESS, Daeδalus, BNCT, etc.
The availability of advanced simulation tools, as well as the synergies with research groups working in the thermonuclear fusion field, allowed to figure out innovative solutions in terms of RF coupling, magnetic field design, mechanics, thus improving in a relevant way the performances and the overall reliability of the systems. An overview of the high intensity proton sources developed since end of Nineties will be given, with particular emphasis to the innovative design of the Proton Source for the European Spallation Source, now entering the commissioning phase at LNS, which is based on a versatile magnetic field system. A specific attention will be paid to modelling and diagnostics efforts, which allow a more advanced mastering of wave-to-plasma interaction and beam formation processes.

Poster session / 2

Surface dependence for laser - induced target current by plastic materials

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Laser - matter interactions are a wide field of physics in which many parameters are involved. A small change in one of them can lead to a completely different time evolution for the physical system. In this work, the characterization of a plastic target subjected to a laser irradiation has been studied. A focus was particularly devoted to the interaction of the target with the whole grounded chamber, which has been tried to be understood through the change of the target - holder surface ratio. The resulting current and particle signals show an anomalous behaviour when this ratio is equal to 1.

Morning Session (Chair: P. Veltri) / 13

Development of a 1 MeV electrostatic accelerator for fusion application at JAEA

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This paper reports the activities on the development of negative ion accelerators for fusion applications at Japan Atomic Energy Agency (JAEA). In International Thermonuclear Experimental Reactor (ITER) and JT-60 Super Advised (JT-60 SA), high-current and high-energy negative ion beams are required to be produced. The beam currents and energies for ITER and JT-60SA are 40A (200A/m2), 1 MeV for 3600 s and 22A (130A/m2), 0.5 MeV for 100 s, respectively. In order to realize those accelerators, an electrostatic accelerator with multiple acceleration stages and apertures has been proposed by JAEA and adopted as the reference accelerators for those.

The accelerator is featured by the use of a large grid with > 1000 apertures for high-current and multiple acceleration stages for high-energy. The major issues are a stable vacuum insulation and a suppression of direct interception loss of the negative ions. A careful experimental studies on the vacuum insulation clarified that the voltage holding is varied with a square root of the gap length between the grids and with a power law scaling of number of the apertures. From the result, the structure of the accelerator has been designed. As for the suppression of the direct interception, the beamlet deflection due to residual magnetic field and space charge are suppressed by an off-set aperture displacement and a “Kerb plate” forming a local compensation electric field. In the test with the ITER mockup accelerator with 9 apertures, a 980 keV, 185 A/m2 has been successfully accelerated for 0.4s in 2011.

Since 2011, JAEA has concentrated on the extension of the pulse duration time. One of the issues is a reinforcement of the extraction grid (EXG), where the extracted electrons are dumped. For this, the cooling channels in the EXG are moved from the previous backside to the front side of the heat receiving surface. This new EXG allows the surface temperature to be reduced to 150 oC of allowable level. In addition, the power loading of the acceleration grids is reduced. The measurement of the power loading in the acceleration grids reveals that the secondary electrons induced by the direct interception of the negative ions with the EXG is one of the origins of the power loading of the acceleration grids in downstream. The EXG is further modified with enlargements of the aperture size and off-set displacement distance.

Taking these measures for the long pulse duration time, the pulse duration time has been successfully extended to 60 s at 0.97 MeV and 190 A/m2. This is the first demonstration of long-pulse acceleration for the ITER- and JT-60SA-relevant intense negative ion beams in the world. The achieved pulse duration time is limited by the capability of the power supply. There is no limitation to extend the pulse duration, namely, no degradation of the voltage holding and beam acceleration have been observed up to 60 s. The further test is planned after the upgrade of the power supply.

Morning session (Chair: A. Faus-Golfe) / 0

Status of the High Intensity Proton Beam Facility at LNL

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In 2013 the SPES (Selective Production of Exotic Species) project has entered in the construction phase at Laboratori Nazionali di Legnaro (LNL). The project, whose main goal is the research in nuclear physics with Radioactive Beams, has foreseen the construction of a new building hosting the accelerator able to deliver protons up the energy of 70 MeV and 700 uA current (50kW of beam power). The new facility design has been expanded and upgraded for taking advantage of the dual simultaneous extraction of beams from the Cyclotron in order to provide a multipurpose high intensity irradiation facility. Today the new facility is partially completed and the Cyclotron supplied by BEST Theratronics company (CANADA) with the related beam transport lines are under commissioning. The status of the commissioning of the high power accelerator and the capabilities of the facility as multipurpose high intensity proton beam laboratory will be presented.

Afternoon session (Chair: M. Cavenago) / 8

Perspectives about the production of multiply-charged ions at high intensities: Innovative schemes of microwave-to-plasma matching

MASCALI, David [1]; CELONA, Luigi Giuseppe [1]; CASTRO, Giuseppe [1]; LEONARDI, Ornella [1]; NERI, Lorenzo [1]; SORBELLO, Gino [2]; TORRISI, Giuseppe [1]; GAMMINO, Santo [1]

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The production of multiply charged ions at medium-high intensity in Electron Cyclotron Resonance Ion Sources requires a trade-off between the plasma density ne and the ion confinement time τi (well known scaling-laws state that I∝ ne / τi while ∝ neτi). Any additional boost of currents with respect to the state of the art (e.g. tens or hundreds μA of Ar14+, Xe34+, etc.), – especially for ions at intermediate charge state – will require a change of paradigm in the plasma generation mechanism. Nowadays the plasma is sustained by an electromagnetic wave resonantly interacting with the plasma electrons, but this implies an intrinsic limitation in density due to the well-known electromagnetic cut-off issue. In the next future, the inner-plasma modal conversion (i.e. microwaves triggering the formation of plasma waves) may support the generation of highly overdense plasmas in simplified magnetostatic field structures. The paper will include recent results obtained at LNS with a compact-size ECRIS prototype in which a highly overdense plasma (ten times the cutoff density) has been generated via O-X-B modal conversion at 3.75 GHz with a low RF power level (<100W). The same techniques may be applied to B-minimum trap with appropriate RF launchers. Advanced diagnostics tools for mastering the conversion mechanism and ensuring the best coupling of the incoming microwave radiation will be described as well.

Morning session (Chair: A. Faus-Golfe) / 9

Experience with a high power cyclotron for radioisotope production

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The Arronax Public Interest Group (GIP) is a facility that hosts a multi-particle cyclotron and several laboratories, dedicated mainly to radio-isotopes productions and also to in-beam experiments for radiochemistry, radiobiology and physics.

The multi-particle cyclotron has been running for these productions and experiments since the end of 2010. Its use has increased over the years reaching more than 4000 hours RF-time in 2015. This required extension of the operation range of the machine over several orders in intensity from 1 pA up to 350 uA for protons on target at several particle energies. The multi-particle capability of the machine is also abundantly used for radionuclide production and radiobiology.

The Arronax facility as well as the cyclotron and its use will be detailed with the scope of radio-isotope production at high intensity. Also the on-going and needed adaptation will be presented.

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Afternoon session (Chair: V. Antoni) / 15

Double beam satellite propulsion

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In this talk I present brief review on a dual beam sources used in space propulsion. Dual beam propulsion is currently represented by few innovative concepts being under development. These concepts promise several advantages to the propulsion, such as precise control of the spacecraft potential, reduced background plasma and removal of a dedicated neutralization system that increases general robustness and mass/dimension property. In addition, dual propulsion concepts have great ability to downscale enabling possibility to use efficient propulsion system for a small spacecraft such as CubeSats and nano-sats.
One of the dual beam propulsion concepts is a PEGASES concept (acronym for "plasma propulsion with electronegative gases") where an electronegative plasma discharge is used to create alternated beam packets of positive and negative ions. Efficient broad beam negative ion extraction is possible due to very high plasma electronegativity i.e. ratio between the negative ion and electron density (reaches 5000); under these conditions plasma response is similar to both positive and negative bias since the electron influence on the sheath formation is negligible. By applying square waveform to the gridded ion acceleration system, positive and negative ions are alternately accelerated up to high velocities (>40 km/s) that provide a thrust force in the direction opposite to the ion acceleration. The generated beam is quasi-neutral, and a spacecraft potential can be controlled by changing a duty cycle of the acceleration voltage waveform. Absence of electrons in the generated beam is expected to reduce background plasma formation, and in addition should decrease beam divergence in a presence of weak magnetic field that can be important for the future missions devoted to targeted space debris removal. Use of this source is however limited to very electronegative propellants, typically based on fluorine, iodine or fullerenes.
Another successful dual beam propulsion concept which will be discussed here is based on an ion-electron source with RF acceleration principle. Briefly, this concept assumes using the plasma self-bias effect in the RF-powered gridded system, providing quasi-simultaneous ion-electron acceleration. Heavy ions are accelerated by an averagely dc electric field, while electrons are co-extracted using the same extraction system in a short moments when oscillating plasma potential reaches low values. First proof of concept is already achieved, demonstrating similar efficiency as for traditional gridded ion thrusters. The ion and electron fluxes emitted by the source are equal helping to achieve much better beam neutralization than in traditional system with neutralizer. The experiments demonstrate that emitted flow of electrons is highly directional, thus the thruster plume can be precisely localized. Strong advantage of this concept is significant technology heritage, because of similarity with the already operated ion thrusters.

Morning Session (Chair: P. Veltri) / 18

Status of NBI for ITER and the related test facility

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Two Neutral Beam Injectors (NBI) will provide a substantial fraction of the heating power necessary to ignite thermonuclear fusion reactions in ITER. The development of the NBI system at unprecedented parameters (40 A of negative ion current accelerated up to 1 MV) requires a strong demonstration activity, which was endorsed by ITER to optimise the crucial components and systems. A test facility, PRIMA (Padova Research on ITER Megavolt Accelerator), is presently in the final phase of construction at Consorzio RFX (Padova, Italy) in the CNR research area and will house two experiments, named SPIDER and MITICA. A full-size negative ion source, SPIDER (Source for the Production of Ions of Deuterium Extracted from
Rf plasma), will be operated in the facility to demonstrate the creation and extraction of a D-/H- current up to 50/60A on a wide surface (more than 1m2) with uniformity within 10%. The second experimental device is the prototype of the whole ITER injector, MITICA (Megavolt ITer Injector and Concept Advancement), aiming to develop the knowledge and the technologies to guarantee the successful operation of the two injectors to be installed in ITER, including the capability of 1MV voltage holding at low pressure. The beam source is the key component of the system, whose design results from a tradeoff between requirements of the optics and real grids with finite thickness and thermo-mechanical constraints due to the cooling needs and the presence of permanent magnets. The experimental effort is supplemented by numerical simulations devoted to the optimisation of the accelerator optics and to the estimation of heat loads and currents on the various surfaces.
In this contribution the main physics aspects of NBIs and the requirements of the test facilities MITICA and SPIDER will be discussed and the design and the status of the main components and systems will be described. Particularly a review of the accelerator physics and a comparison between the designs of the SPIDER and MITICA accelerators will be presented.

Afternoon session (Chair: M. Cavenago) / 19

Thruster for satellite propulsion and negative ions

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Low pressure ExB partly (electron) magnetized plasmas plays a key role not only in different plasma-based devices, such as Hall-effect thruster and negative ion source. In the first, the magnetic field allows a better electron confinment increasing the propellant ionization and ion acceleration efficiencies, while in the second the magnetic filter field allows the electron temperature and density reduction increasing the survival probability of negative ion and reducing the coextracted electron current. Nevertheless, unwanted phenomena occur related to self-orginized structures formed in the region of high magnetic field: azimuthal fluctuation in Hall-effect thruster and plasma asymmetry in negative ion source lead to increased electron cross-field transport. In this contribution results from self-consisted particle-based models will be presented and discussed considering optional alternative configurations.

Morning Session (Chair: P. Veltri) / 12

Development, injection and diagnostics for LHD Injectors

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Neutral beam injector (NBI) is the most powerful and reliable plasma heating device in the nuclear fusion research. The NBI is essential to sustain plasma current generating the confinement magnetic field in TOKAMAK machines such as ITER and JT-60SA. In National Institute for Fusion Science (NIFS), two positive-ion-based NBI (p-NBI) and three negative-ion-based NBI (n-NBI) are installed to improve the performances of plasma confined in Large Helical Device (LHD). The p-NBI and n-NBI are designed to inject the beams to LHD hydrogen plasmas with the energies / powers of 40 keV / 6 MW and 180 keV / 5 MW, respectively. The farmer injectors generate low temperature background LHD plasmas and are also applied for diagnostic beams to measure ion temperature. The later injectors heat up the background plasmas generated with p-NBI. The designed beam energies and powers have been successfully achieved. Using those injectors, many important achievements related to current drive, high ion temperature, L-H transition and high β plasma experiments have been achieved.
As the next phase of LHD experiment, we have scheduled deuterium plasma confinement Filament-arc discharge is applied to generate plasmas in the magnetic configuration. The energy of the p-NBI systems are increased up to 60 keV and 80 keV with the injection power of 9 MW. On the other hand, the beam energy of n-NBI systems are fixed their energy and so that the current densities of deuterium negative ions are needed to be enhanced. In order to understand the detailed mechanisms of negative ion production and its extraction, comprehensive diagnostics for the hydrogen plasma in an ion source has been started. In the beam extraction region, ion-ion plasma, whose electron density is less than 1 %, are formed by seeding caesium (Cs) in the plasma. Response of the ion-ion plasma to electrostatic field is very different from normal electron-positive ion plasma and the shielding character to the electrostatic field depends on the magnetic structure. In the diagnostics, we have measured the spatial distributions of densities, flows and temperatures of electrons, positive and negative ions. Taking into account the energy relation of incident and out going particles, parent particle of negative ion is proton using our experimental results. Electrons and positive hydrogenous ions transport via ambipolar diffusion from plasma generation region to caesieted surface for negative-ion production, plasma-grid surface. The energy of negative ion have very low energy of ~0.1 eV.
The diagnostic results indicate that the negative-ion production is not governed with particle picture and the production rate is not controllable by bias potential applied to the plasma-grid surface. This suggests that geometric or magnetic structures are necessary to change to increase negative-ion yield. A new structure of plasma grid to produce negative ion will be discussed.

Poster session / 14

High current negative ion source with Planar Funnel extraction grid

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High current large negative (H-, D-) ion sources will produce the neutral beams needed for fusion plasma heating in ITER. To reach very high negative ion beams a cesium coated surface of the plasma grid is usually used. The cesium coating however, poses some problem in the maintenance and operation of the ion source and for that alternative ways to enhance the ion current extraction should be investigated. An alternative way to enhance the beam current could be the use of a Planar Funnel Extraction (PFE) grid recently proposed for applications where a very high extraction efficiency are required [1]. In this contribution the idea of applying the PFE to a negative ion source instead of the cesium coating will be discussed.

[1] A. Chaudhary et al., Review of Scientific Instruments 85, 105101 (2014); doi: 10.1063/1.4897480

Morning Session (Chair: P. Veltri) / 25

Discussion D1: new concepts and spin-off of fusion injectors

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May the large effort in developing powerful ion sources and accelerator
produce some spin-off? Which application area?

Questions on simulation of multicomponents plasmas (H/D/Cs, 3rd day discussions) and other session topic are also welcomed.

Minutes prepared by conveners (P. Veltri, M. Cavenago) may be posted on the website, as well as short presentations (3 slide max) received for the discussion.

Afternoon session (Chair: M. Cavenago) / 5

Recent results of NIO1 negative ion source and future improvements

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Neutral Beam Injectors (NBI) based on negative ion conversion are fundamental to increase the plasma temperature in magnetic confinement fusion devices.. In the framework of the accompanying activities in support to the ITER NBI test facility a relatively compact radiofrequency (RF) ion source, named NIO1 (Negative Ion Optimization phase 1) is being developed and tested in Padua, Italy, in collaboration between Consorzio RFX and INFN. This contribution reports the recent status of the experiment, including the operation in air and oxygen and the first beam measurements. Future improvements to enhance the negative ion current and reduce the amount co-extracted electrons are also discussed.

Afternoon session (Chair: M. Cavenago) / 29

Discussion D5: dissemination of result and/or next workshop

Future publication of the conference results can be discussed, as well as ideas for new workshop themes in the Accelerator Application Network of the EUCARD2 project, and general questions.

Closing remarks will follow.

Minutes prepared by convener(s) may be posted on the website, as well as short presentations (3 slide max) received for the discussion.

Poster session / 31

Recent results of NIO1 negative ion source and future improvements (P. Veltri; also talk O17, ID=5)

Morning session (Chair: A. Faus-Golfe) / 33

Discussion D3: application of accelerators

Which applications of accelerators will benefit from large current?
Which perspectives for development?
Which new collabaration themes (between partecipants) can be identified?

Minutes prepared by convener(s) may be posted on the website, as well as short presentations (3 slide max) received for the discussion.

Poster session / 32

Review of LNL Accelerators for Applied Physics: AN2000, CN and related experiments (S. Canella, see also talk O10, ID=6)