RECENT RESULTS OF PHOENIX V2 AND NEW PROSPECTS WITH PHOENIX V3*

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Abstract

The 18 GHz PHOENIX V2 ECRIS is running since 2010 on the heavy ion 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 (LCO) 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 approved 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 is presented along with a status of the project.

PHOENIX V2 RECENT RESULTS

The PHOENIX V2 source is an evolution of the former PHOENIX V1 source used to study intense pulsed afterglow Lead beams for the LHC [1,2,3]. Major improvement of V2 with respect to V1 are a higher voltage withstanding (60 kV) and a higher radial magnetic confinement (1.35 T instead of 1.2 T at plasma chamber wall); the drawback being a lower chamber volume (0.7 liter instead of 1.2). Information on the 3 PHOENIX version layout is reported in the next section for completion. PHOENIX V2 was installed at LPSC on the SPIRAL2 LEBT from December 2009 until June 2012 and allowed the successful beam line commissioning. Production tests of A/Q=3 beams have been performed with gas and metals in collaboration with IPNL and GANIL. The table 1 summarizes the results obtained. The beam results increased recently by 30% after the discovery and the fixing of a wrong mechanical part machining in the plasma chamber water flow circuit. Once fixed, the water flow reached its nominal value and the source immediately accepted much more RF power to produce further high charge states ions. The Fig. 1 presents a Ni spectrum obtained with the GANIL LCO. [4] The Ni consumption was 0.2 mg/h and beam featured stable behaviour for several hours. One should note the excellent charge state distribution peaked on the 19+ which was unexpected for such a compact source. The 20 μA Ni^{19+} was obtained at the upper LCO operation temperature and no intensity saturation was observed. So a higher Ni^{19+} current should be reached with 2 ovens set in parallel or a larger oven. Unfortunately, the 32 mm source radius is too small to allow this. The key to understand this high charge state distribution is likely the pressure decrease in the plasma chamber induced by the Ni vapor (Getter effect). Indeed, the plasma chamber is only pumped through the plasma electrode. The vapor to ion yield was measured to be ~10%. The LCO is located off axis with an angle that optimizes the vapor solid angle intersection through the ECR plasma.

Table 1: Intensities Produced by PHOENIX V2

Ion	Charge state	Intensity [μA]
He	2+	2400
O	6+	1300
	7+	250
Ar	12+	205
	14+	50
Ni	19+	20
	20+	11.5
	21+	5

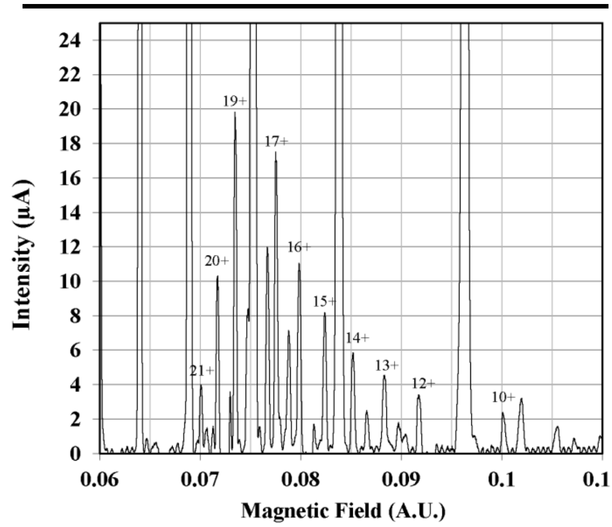

Figure 1: Nickel spectrum obtained with PHOENIX V2.

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PHOENIX SOURCES AND V3 UPGRADE

The PHOENIX Source Series

The PHOENIX source series have been developed at LPSC since 1997. The series is composed of PHOENIX BOOSTER, PHOENIX CERN (V1), PHOENIX V2; A-PHOENIX, and shortly PHOENIX V3. [1,2,3,5,6] The Table 2 presents the main parameters of these sources. Apart from A-PHOENIX, the room temperature PHOENIX series is based on the same axial coil geometry and high voltage isolation concept. A set of Axial coils and iron disks are stack together to reach the desired axial profile length and intensity, then clamped together with large threaded rods. A rigid 3 mm thick HV cylinder isolator is placed afterward in the resulting warm bore. The central HV core, composed of the permanent magnet hexapole, the plasma chamber and 2 clamped iron plugs, is inserted inside the insulator. Finally, two (or one for the BOOSTER) axial insulating rings are added at each end to clamp the inner HV core part to the outer grounded part (see [3]). The PHOENIX V2 sectional view displayed on Fig. 2 illustrates the unique PHOENIX geometry. In earlier time, the swapping of iron disks and coils set in the stack allowed studying the best experimental axial confinement configuration. Another advantage is the possibility to design new source core and replace it very quickly inside the source.

Table 2: PHOENIX Source Series

PHOENIX SOURCE	Magnetic Confinement		Plasma Chamber geometry			f_{ECR} [GHz]	High voltage
	Axial mirror [T]	Radial field at wall [T]	Length [mm]	Radius [mm]	Volume [liter]		
BOOSTER	1.2-0.4-1	0.8	300	36	1.2	14	25
CERN (V1)	1.6-0.7-1.3	1.2	300	36	1.2	28	55
V2	2.1-0.47-1.28	1.35	210	32	0.7	18	60
A-PHOENIX	3-0.7-3	1.55-2	400	32.5	1.3	18-28	60
V3	2.1-0.47-1.3	1.1-1.32	220	45	1.3	18	60

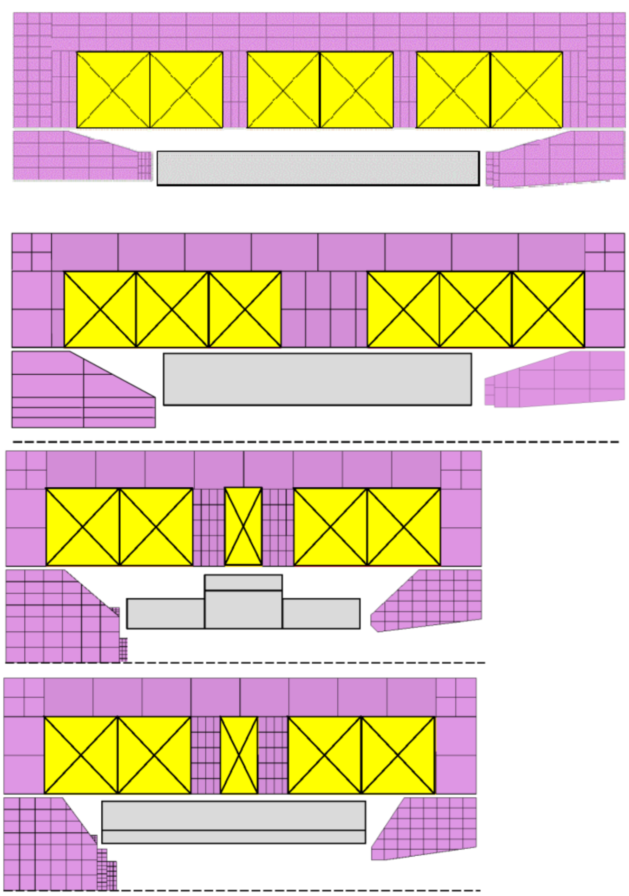

Figure 2: From top to bottom: sectional view of PHOENIX BOOSTER, CERN (V1), V2 and V3.

Volume Effect on A/Q=3 Beam Intensity

The Fig. 3 presents the evolution of O^{6+} and Ar^{12+} A/Q=3 ion beams as a function of several ion sources plasma chamber volume. [7,8] Apart from any ECR heating frequency consideration, a clear volume effect is visible in the plot. One should note firstly the results obtained for Ar^{12+} beams at 18 GHz for three different source chamber volume: PHOENIX V2 (0.66 l), GTS (1.5 l) and SUSI (3.3 l) featuring a linear increase of the beam intensity as a function of the chamber volume (see red dashed line). It is clear that at a given ECR frequency, a higher chamber volume with the appropriate magnetic confinement provides a larger ECR surface. For a given power density, the ion production rate is thus enhanced due to the higher ECR surface in a larger volume ECRIS. A large plasma chamber volume also provides a higher confinement time for both ions and electrons since the particle trajectories along field lines are longer from wall to wall. Consequently, the charge state distribution shifts to higher charge states, which favours A/Q=3 beam production. The larger volume sources points plotted corresponds to SECRAL and VENUS, operated at higher frequency (24-28 GHz) with possibly a double frequency heating. One can note that the A/Q=3 beam intensity results obtained for these latter sources are lower what the frequency scaling law predictions. For instance, the 700 μA Ar^{12+} beam obtained with SUSI would correspond to ~1700 μA at 28 GHz, while the best result obtained so far is 860 μA with the VENUS source operated at 18+28 GHz. A part of this intensity difference may come from the difficulty to manage the beam extraction and

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transport of such high intensity beams (present high voltage limitation of existing sources, power supply drain current limitation, RF power limitation, increase of magnetized beam emittance,etc.). Obviously, the know-how at 18 GHz operation is much developed than at higher frequency, and possible improvement at 24-28 GHz may occur in the future.

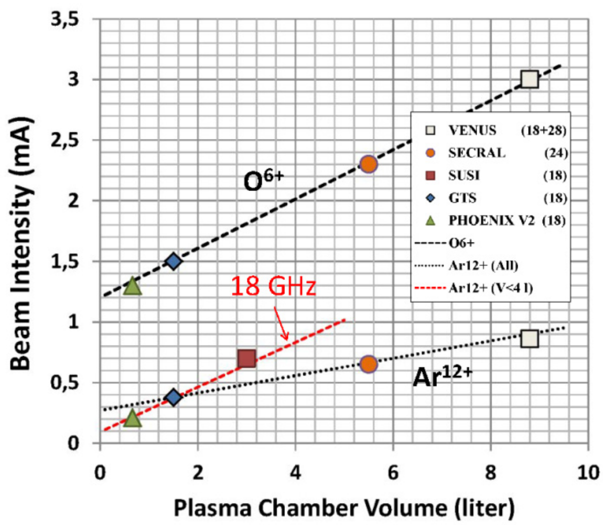

Figure 3: A/Q=3 beam current evolution for various ECRIS as a function of the chamber volume.

The PHOENIX V3 Upgrade

The prospect to improve the existing performance of the PHOENIX V2 source is of high interest for the SPIRAL2 physics experiments. Helped with the PHOENIX concept flexibility, a new serial source named PHOENIX V3 is under design to multiply the chamber volume by 2 with respect to the V2, keeping the magnetic confinement intensity at wall practically unchanged (see Fig. 2). The axial magnetic structure of the two series is practically identical in order to simplify the switch from V2 to V3. Thus, only the central HV core (composed of the two iron plugs, the hexapole and the plasma chamber) is changed. This will allow swapping the source core during operation, depending on the type of beam required by the physics: PHOENIX V2 for gas beams and PHOENIX V3 for metallic beams. The main difference between V2 and V3 is the inner radius of their permanent magnet hexapole (32 mm for V2 and 45 mm for V3). The two hexapole cross section views are displayed in Fig. 4. Both are classical Hallbach type hexapole with 36 magnets per turn. The V2 and V3 radial magnetic intensity at wall along the source axis z are plotted on Fig 4. The V2 hexapole features a hat sectional shape (see also Fig. 2) which delivers 1.35 T at the center and 1.1 T on both injection and extraction region. While the V3 profile is more homogeneous, with a flat intensity of 1.3T. The radial profile of V2 and V3 as a function of the radius is presented in the Fig. 6. the chamber walls are indicated by dashed lines for the two sources. One should note that the two hexapoles have the same outer diameter, since they both need to fit in the axial structure bore. The capacity to keep the V3 field intensity at R=45mm wall nearly identical to the V2's one at R=32 mm is obtained using the technique developed and checked on A-PHOENIX [6], technique in turn derived from the MMPS technique. [9] In V3, the inner stainless steel cylinder holding the permanent magnets is 1.5 mm thick and features 6 slits along the hexapole poles in which 6 mm large iron plates are welded. The iron plates fully saturate at 2.1 T and provide the requested 1.3 T intensity 2.5 mm away on the inner aluminum chamber cylinder wall as plotted on Fig.7. The plasma chamber cooling is performed by a water flow located between the two cylinders. A thin protection to prevent iron corrosion is foreseen. The inner aluminum cylinder would come apart for cleaning purpose. The V3 hexapole length is 270 mm, being 30 mm longer than the V2 one. The two axial iron plugs geometry has been modified accordingly to provide a higher radial intensity at wall at the axial peak fields locations (see Fig. 2 and 5).

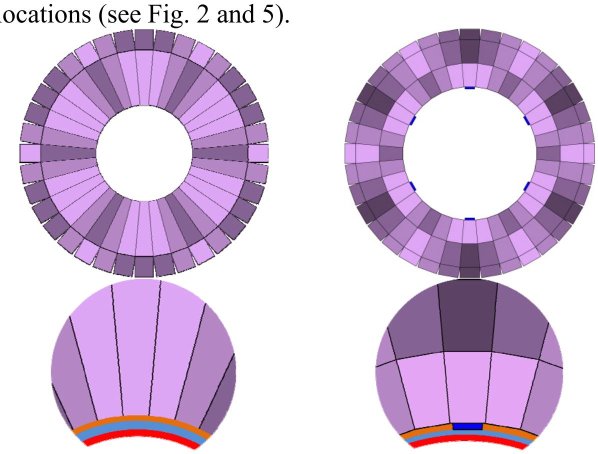

Figure 4: Up: Hexapole cross section of PHOENIX V2 (left) and V3 (right). Down: zoom on plasma chamber detail for V2 (left) and V3 (right).

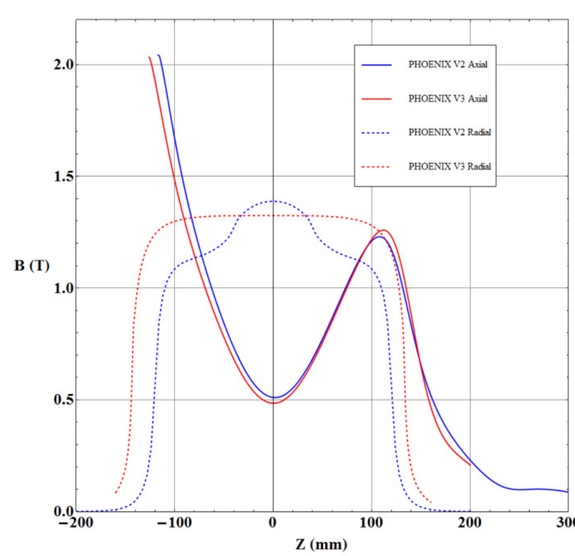

Figure 5: Axial (solid line) and radial (dashed line) magnetic field intensity along the source axis. Wall generated by the sole hexapole (dashed). Red and blue curves stand respectively for PHOENIX V3 and V2.

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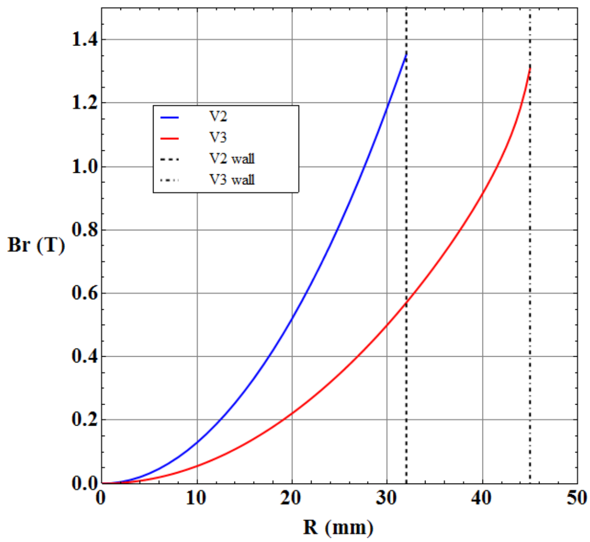

Figure 6: radial magnetic intensity in the center of the source generated by the hexapole as a function of the radius for PHOENIX V2 (blue) and V3 (red). Dashed lines stand for plasma wall position.

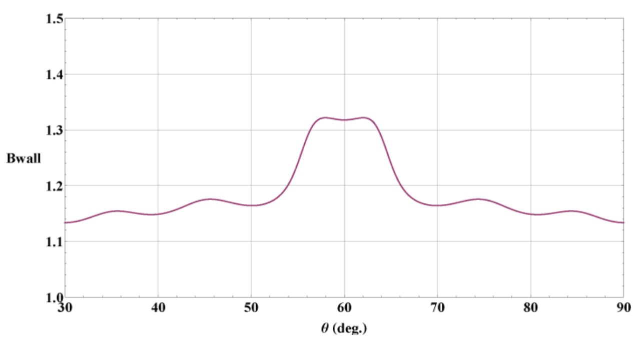

Figure 7: Magnetic boost along the wall induced by one the iron plates, as a function of the azimuthal angle (θ=60° is a main pole, next pole would be θ=120°, r=45 mm, Z=0 mm (centre of the source)).

FUTURE PROSPECTS

A comparison of the ability to produce and extract ions from both PHOENIX V2 and PHOENIX V3 will be performed by simulation in collaboration with GSI. This would give an interesting relative information on how the plasma chamber volume influences ion formation and extraction. The mechanical design study of PHOENIX V3 is foreseen to be completed by the first semester of 2013. The commissioning of the new source should begin during the second semester of 2013.

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