Negative Ion Radio Frequency Surface Plasma Source with Solenoidal Magnetic Field

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ABSTRACT

- Operation of Radio Frequency surface plasma sources (RF SPS) with a solenoidal magnetic field are described.
- RF SPS with solenoidal and saddle antennas are discussed.
- Preliminary dependences of beam current and extraction current on RF power, gas flow, solenoidal magnetic field and filter magnetic field are presented.

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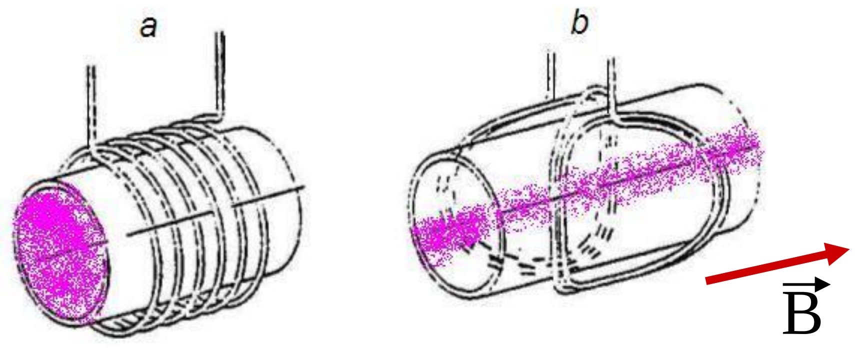
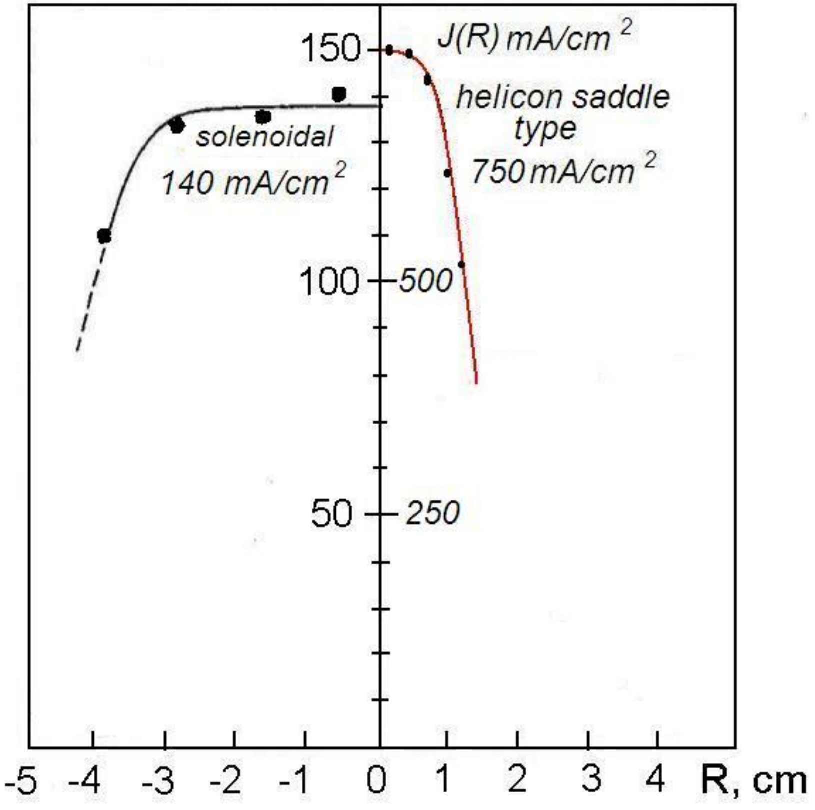
Efficiency of plasma generation in a Radio Frequency (RF) ion source can be increased by application of a solenoidal magnetic field. The specific efficiency of positive ion generation was improved by the solenoidal magnetic field, from 5 mA/cm^2 kW to 200 mA/cm^2 kW. Chen presented an explanation for the concentration of plasma density near the axis by a magnetic field through a short circuit in the plasma plate [*D. Curreli and F. Chen, Equilibrium theory of cylindrical discharges with special application to helicons, PHYSICS OF PLASMAS, 18, 113501 (2011).*]. Additional concentration factor can be a secondary ion-electron emission initiated by high positive potential of plasma relative the plasma plate. Secondary negative ion emission can be increased by cesiation-injection of cesium, increasing a secondary electron and photo emission.

Antennas of RF plasma generator



a- ordinary solenoidal antenna with plasma generation on the large radius;

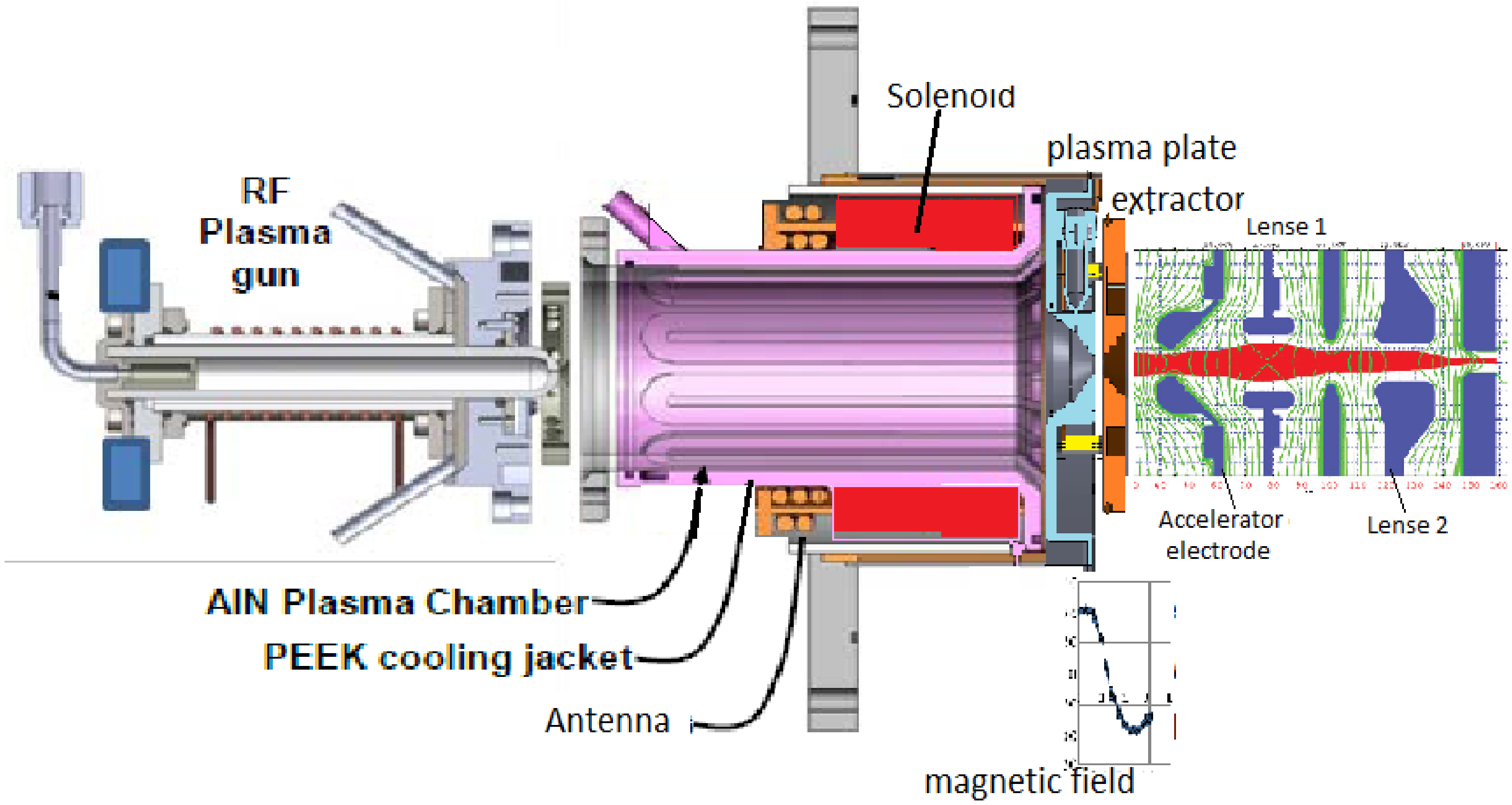
b- saddle type antenna with plasma generation on the axis. Magnetic field is along the axis of cylindrical discharge chamber.



Ion flux distribution for discharge with ordinary solenoid (left) and with saddle type RF antenna (right).

RF power ~2.7 kW, RF frequency ~5 MHz, magnetic field 70 Gs

RF SPS with a solenoidal magnetic field was tested at SNS test stand with ELEBT



The RF ion source consists of an AlN ceramic chamber with a cooling jacket from keep. At the left side, an RF assisted triggering plasma gun (TPG) is attached. At the right side, a plasma electrode with an extraction system is attached. The discharge chamber is surrounded by a saddle (or solenoidal) antenna. .The LEBT at the right side consists of an accelerator electrode and two electrostatic lenses which focus a beam into a 7.5 mm diameter hole in the chopper target.

Lant=4.3 mcH

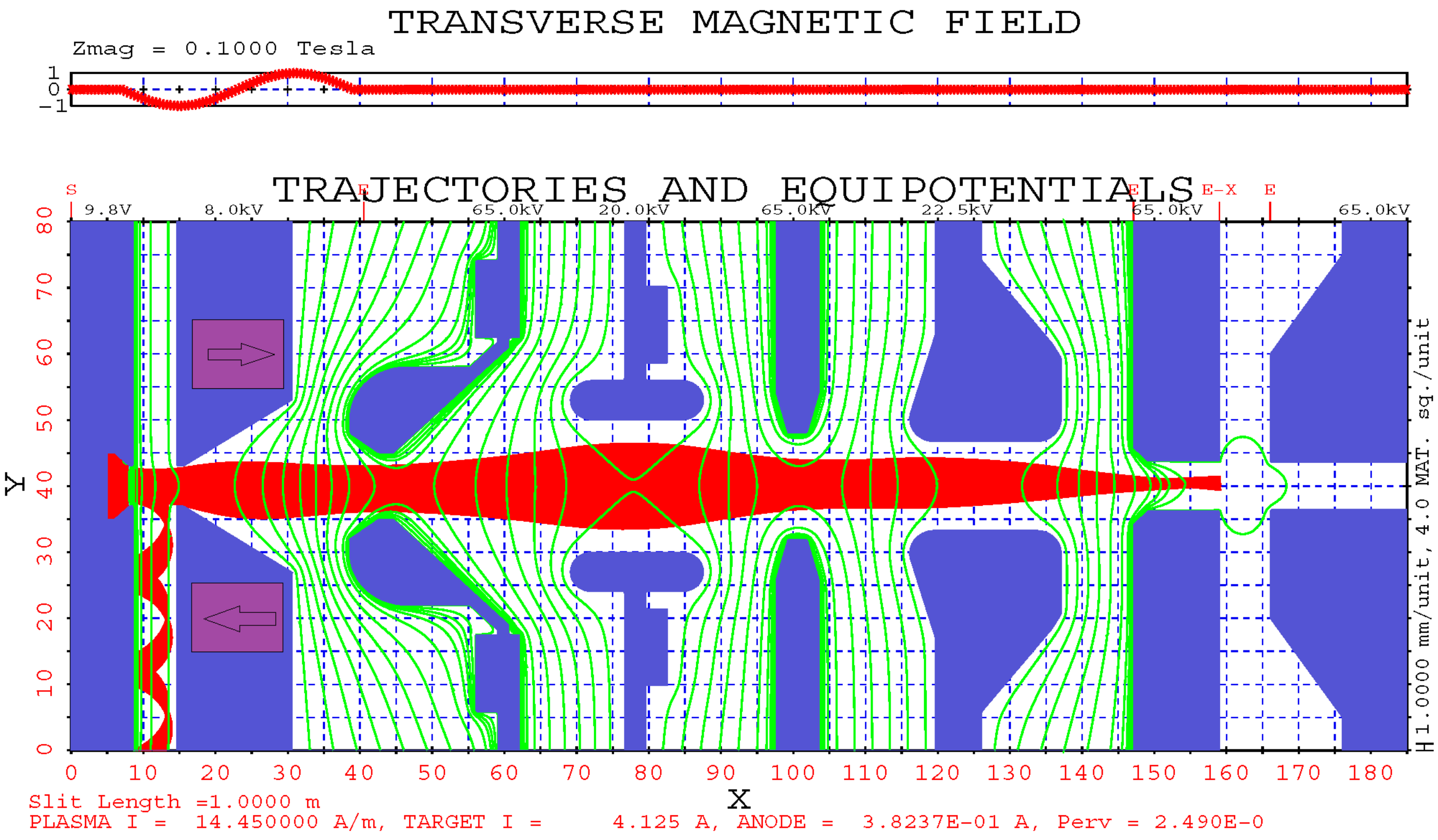
Start discharge at 2 MHz, at Prf=15%, <I>=293 mV, P=3.8 kW; Iant=120 A. U=6.5 kV.

At 13.56 MHz discharge start

At P=0.5 kW, Iant=14 A, U=1.2 kV.

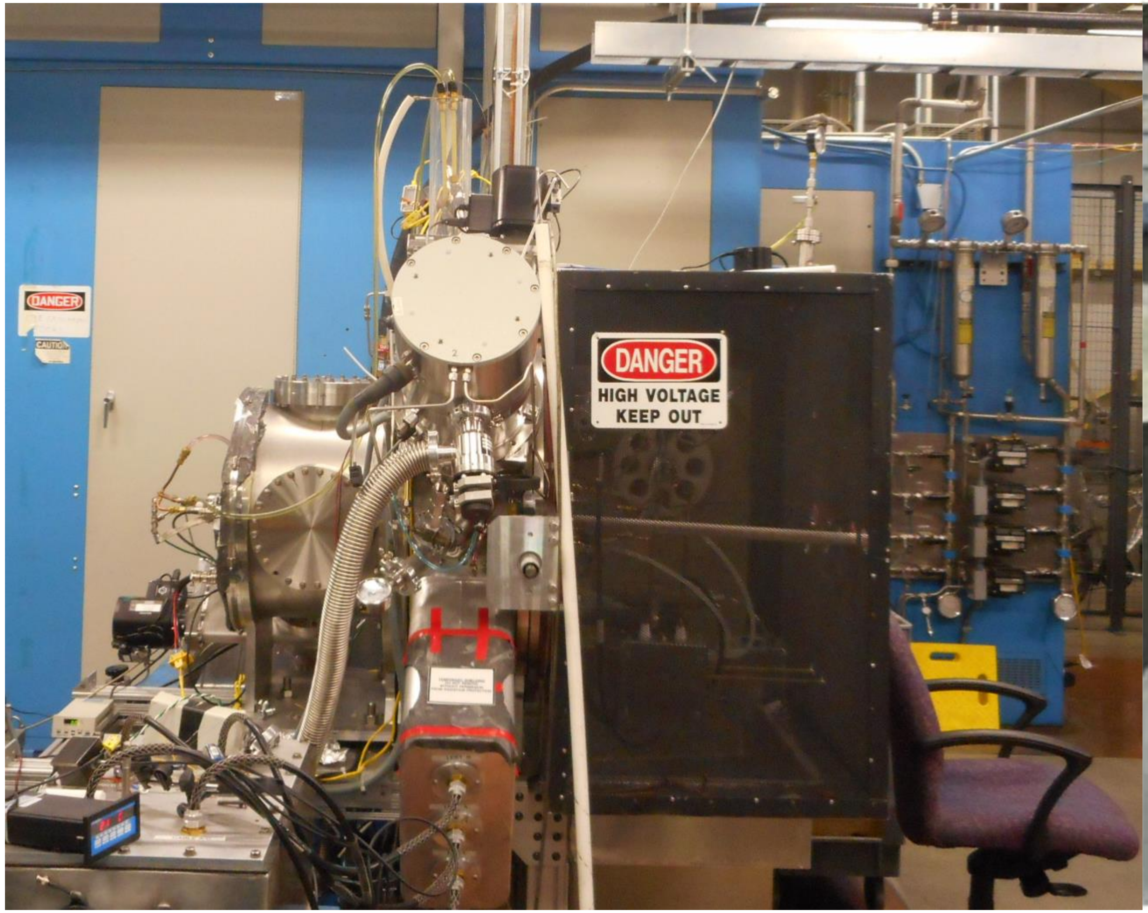
Q=24 sccm.

Simulation of high current beam extraction/transport with ELEBT in the SA RF SPS.

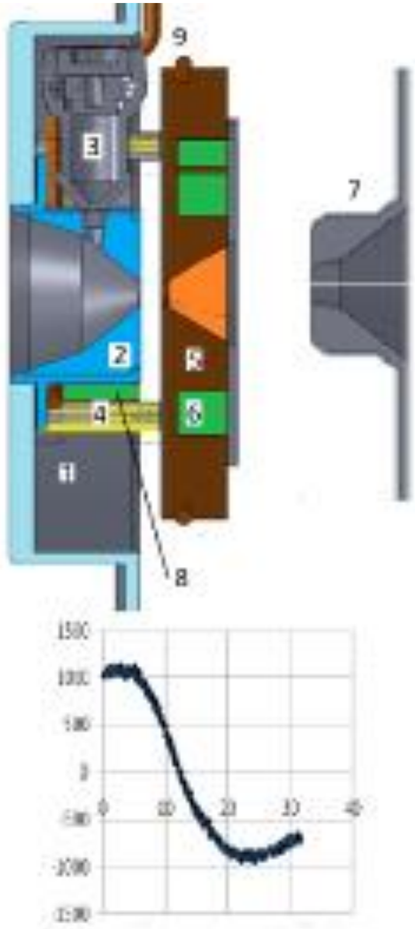


New solenoids

SNS test stand

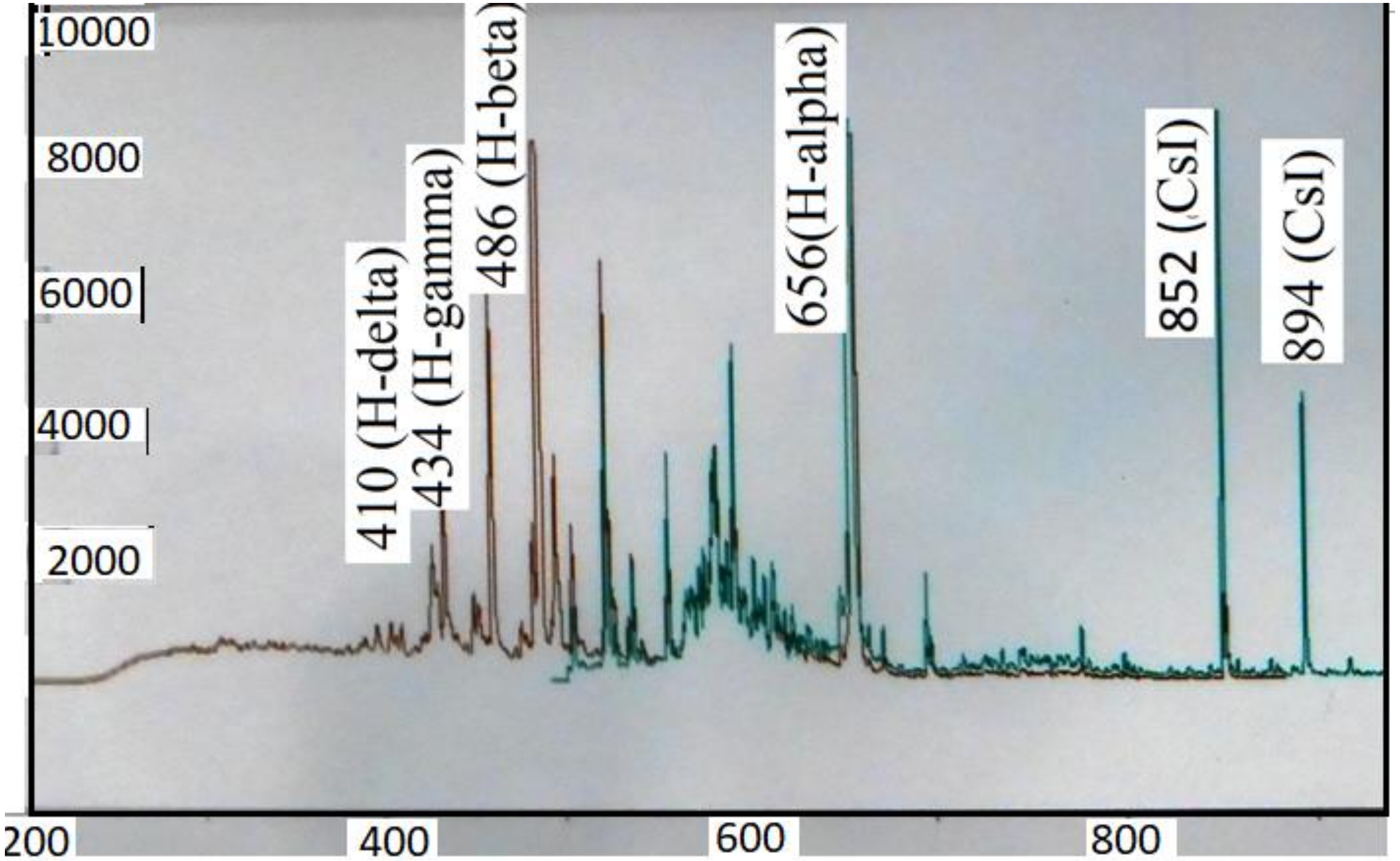


Extractor (e- dump) with Cs oven and transverse magnetic field (strong filter field)



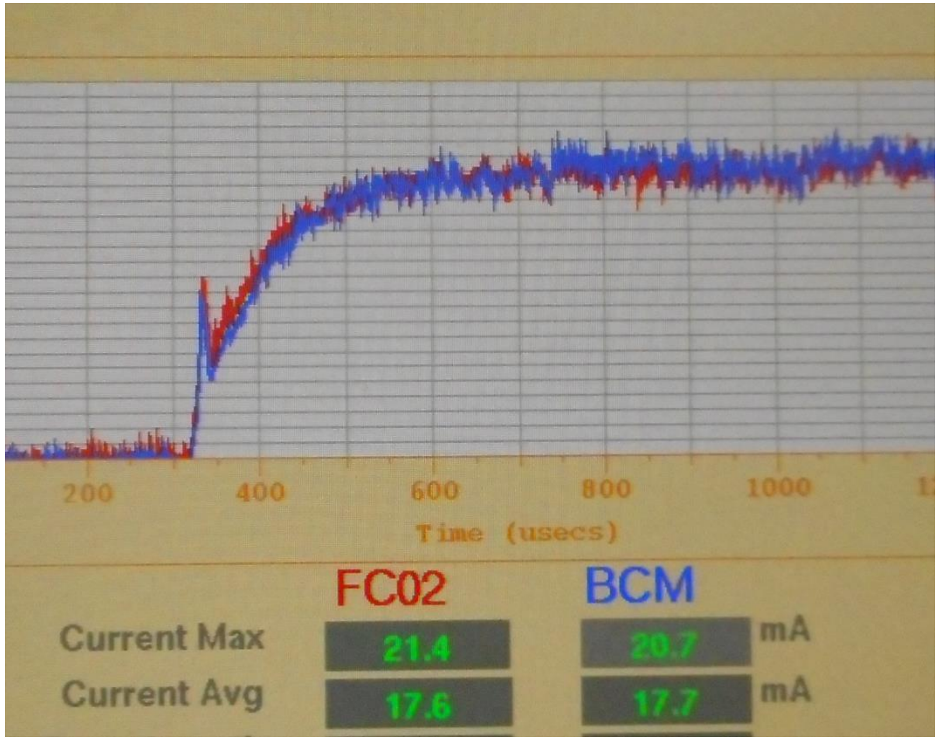
Plasma plate with conical collar, Cs oven and ceramic insulators

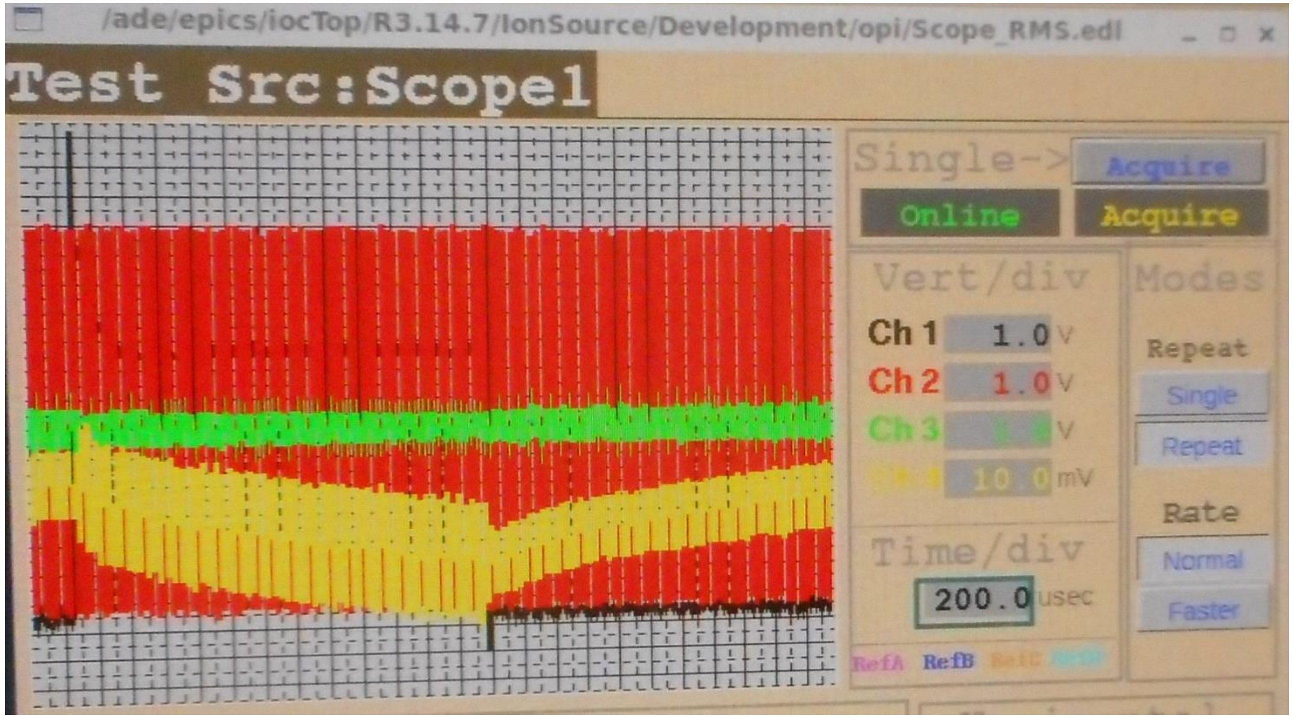
Cesiation spectrum



Picture of extraction and LEBT during cesiation LEBT is shined, but current didn't increase too much

Faraday cup signal and e-dump signal





FC signal Ifc~20 mA.

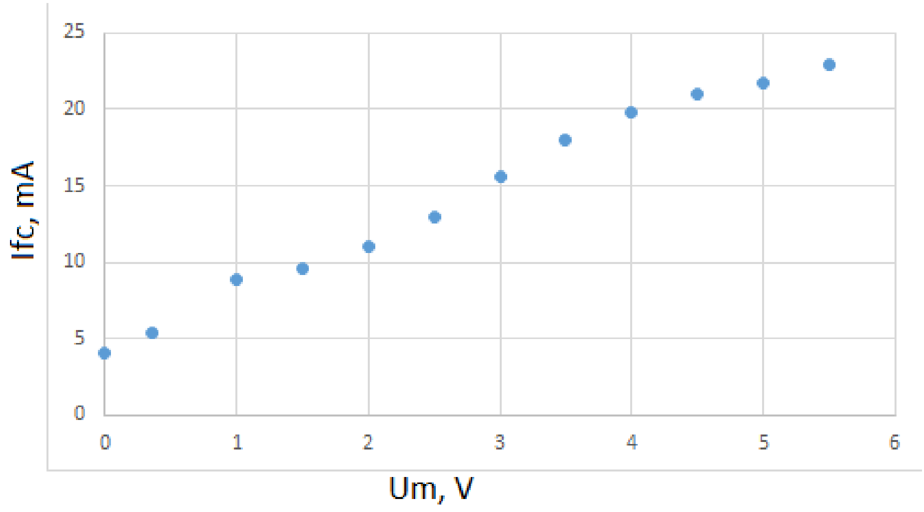
E-dump signal Ie~8 mA.

Cesiation is good.

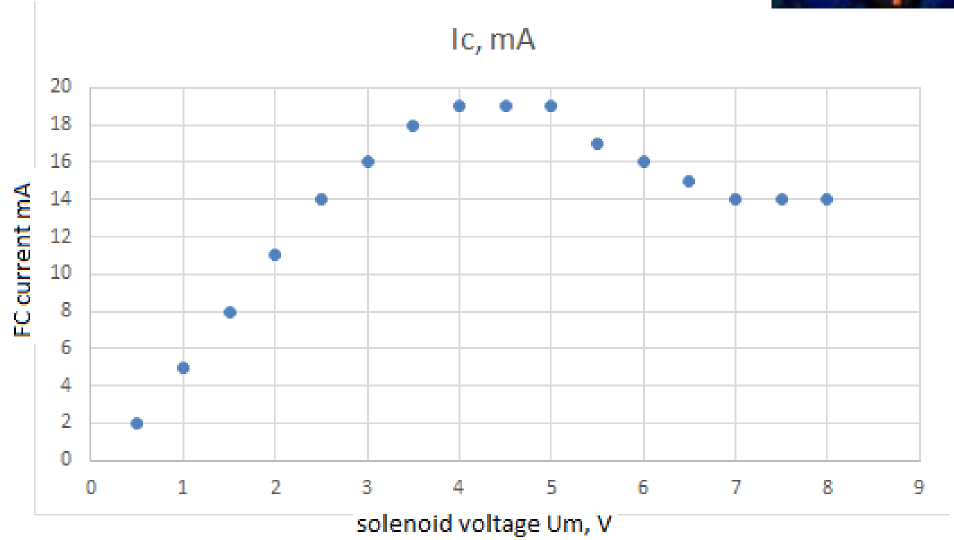
Strong transverse magnetic field ~1 kG attenuate a plasma flux.

No change at variation of Tcoll 30-430 C.

Dependence of FC current on solenoid voltage

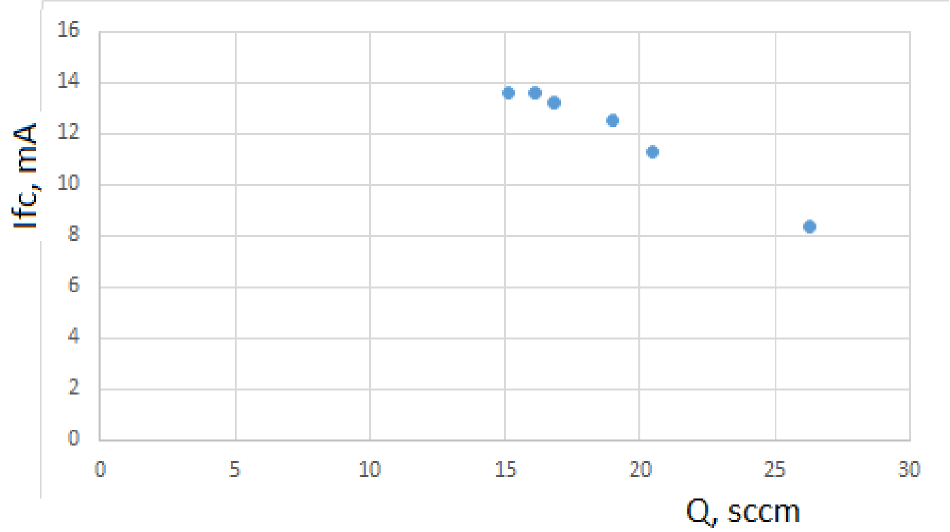


With a saddle antenna



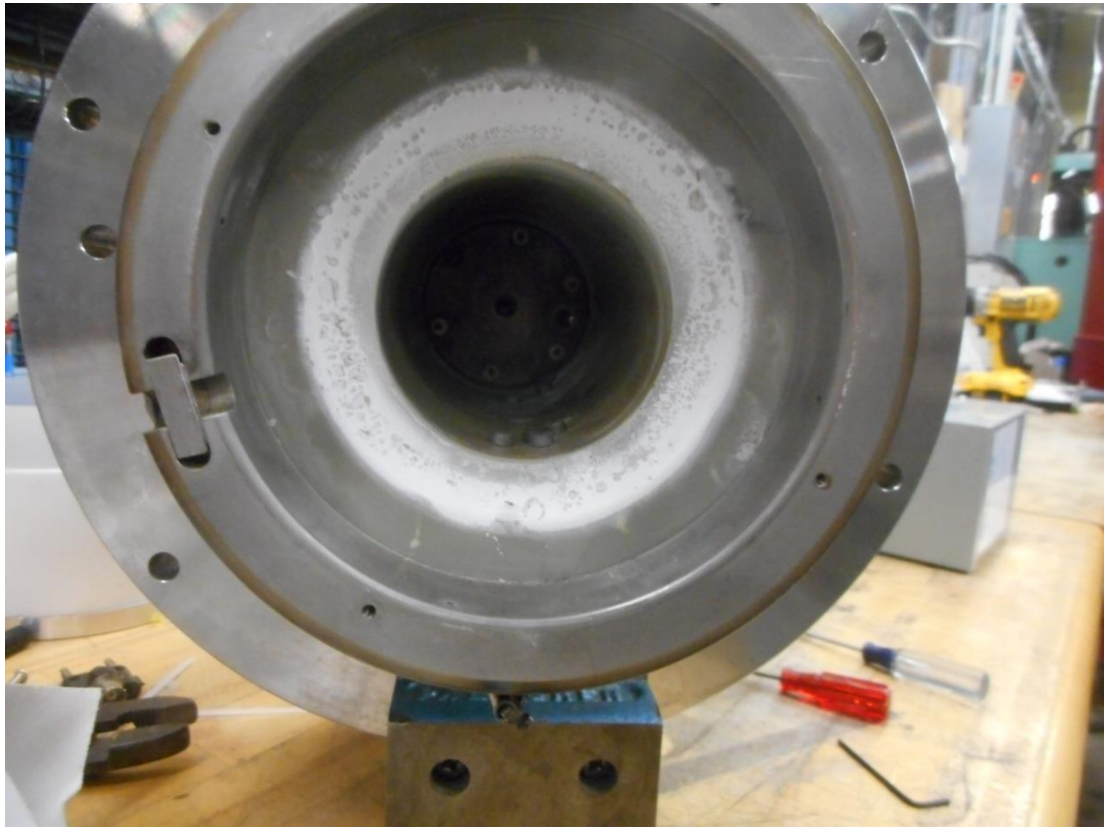
With a solenoid antenna

(UM=7 V corresponded Bs=250 G)

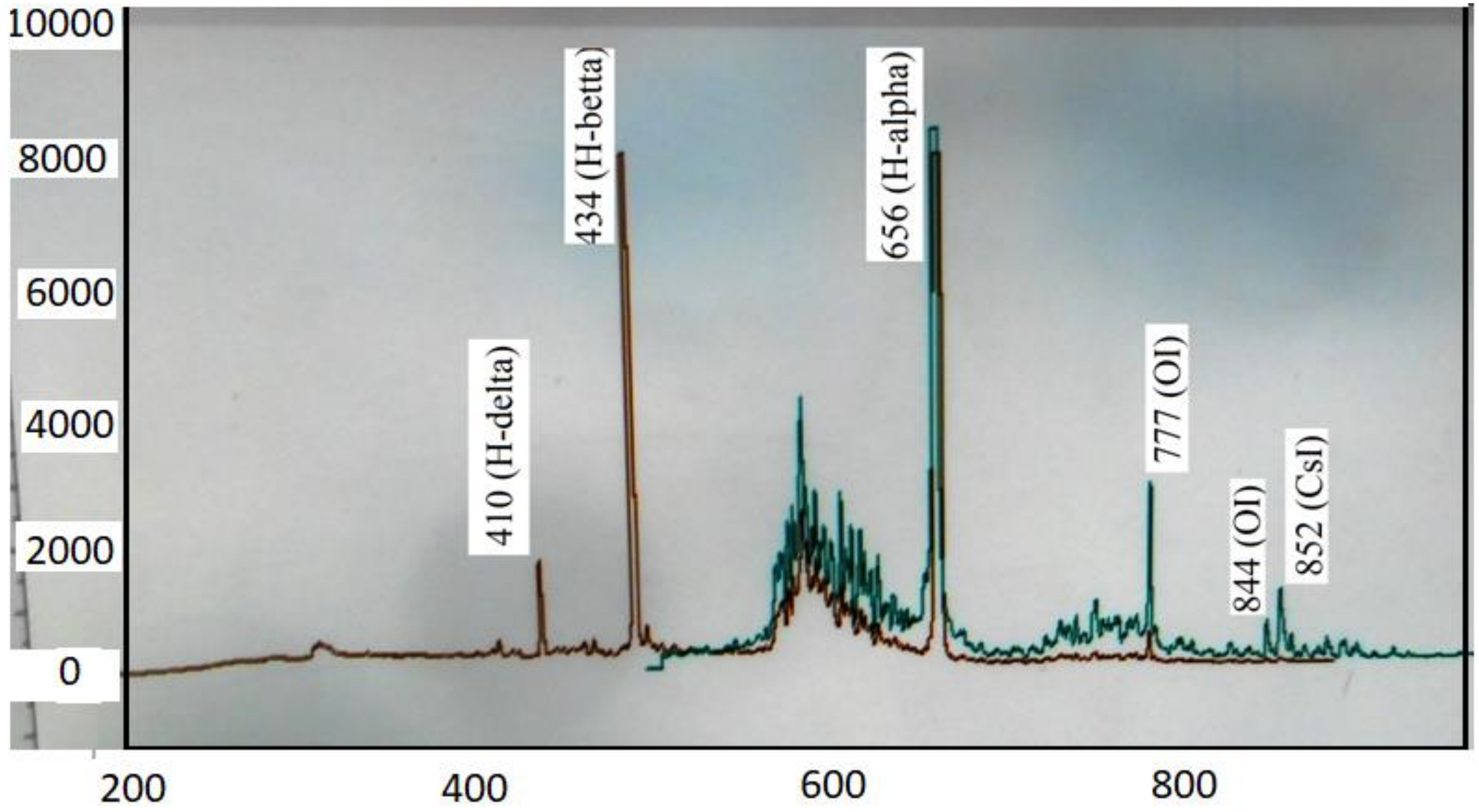


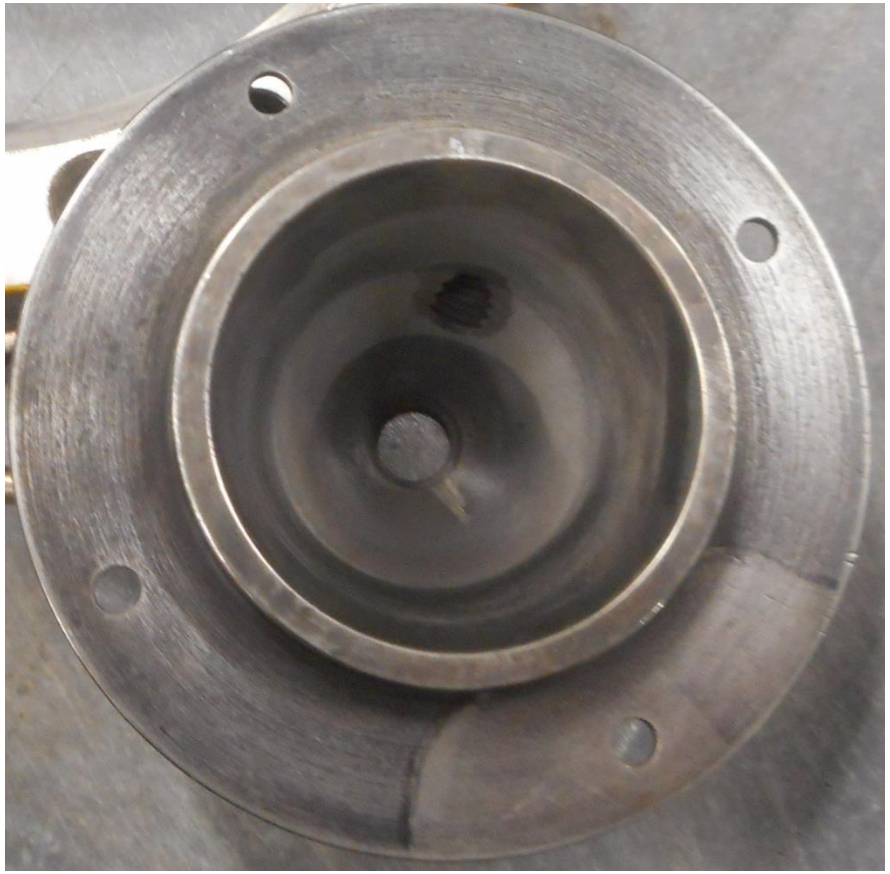
Dependence of beam intensity Ifc, mA on Gas flow Q sccm

CsH deposited on discharge chamber not treated by discharge (Cs pellets inside)



Conditioning with high concentration of Oxygen (from water)



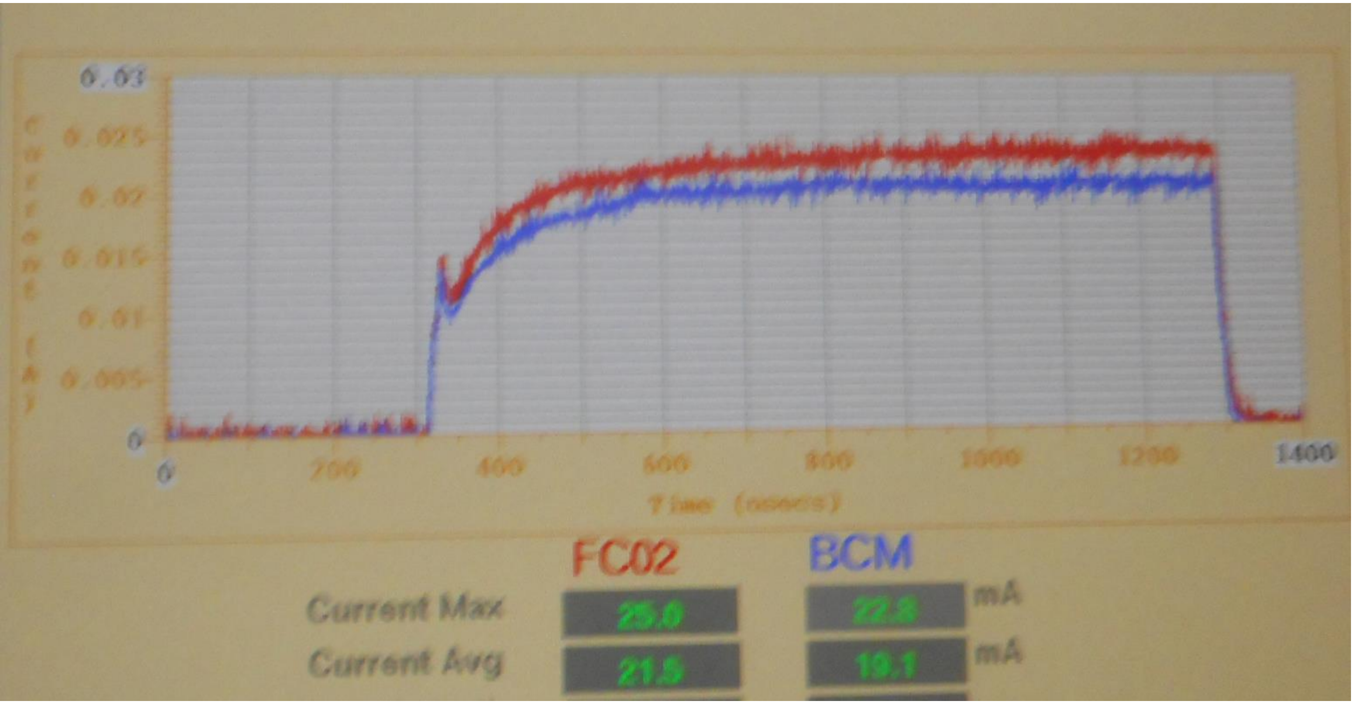


Conical collar with a dark deposition around the emission aperture

Oscillogramms of current of 65 kV power supply (1) 1V/A

Oscillogramms of extractor current (3) at 1 V/A

Oscillogramms of current to chopper target (4) at 50 Ohm



Oscillogramms of Faraday cup current Ifc=25 mA

Forwarded RF power from the RF generator is measured by a directional coupler and calculated by the following formula:

$P_{rf}=45 \times \langle I\rangle^2$ kW, where $\langle I\rangle$ is rms current in V. Before triggering discharge, all power is dissipated in the insulating transformer, antenna and matching network. For our case it is $\langle I\rangle=0.293$ V, 3.86 kW, antenna current $\langle I\rangle_{ant}= 83.3$ A, antenna voltage V=6,480 V. Active resistance of network + antenna is $R=2P/\langle I\rangle^2_{ant} =2*3860/(83.3)^2=1.1$ Ohm. For discharge with $\langle I\rangle =0.599$ V the power Prf=16 kW is dissipated in discharge Pd, in antenna+network P_{ant} and in surrounding antenna solenoid P_{sol}: $P_{rf}=P_d+P_{ant}+P_{sol}$. For $\langle I\rangle_{ant1}=136$ A $P_{ant}=R\langle I\rangle^2_{ant}/2=10$ kW.

Loss in solenoid: Tsol=62°C; Tsol=34°C; DT=28°C

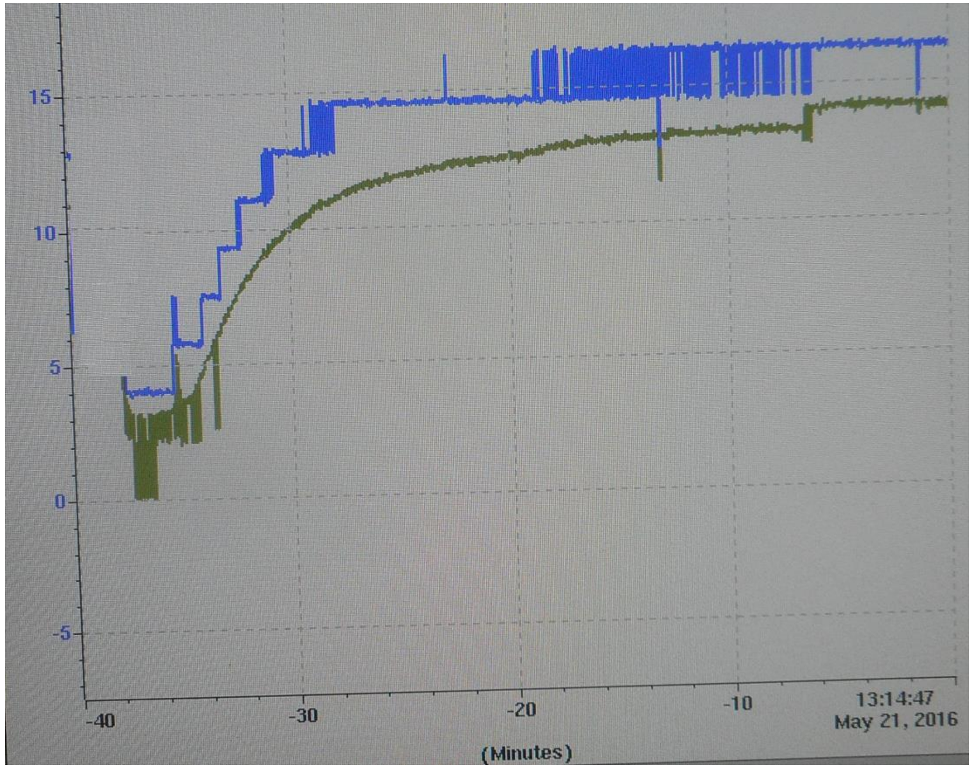
Um=1.68 V; Tsol=34°C; Tsol=32°C; DT=2°C. R=0.15 Ohm. P=U2/R=18.8 W; DT/P=0.1 C/W. RF loss in solenoid DT/0.1=280 W; Pulse power loss 280x100/6=4.6 kW, for 50%.

RF voltage-2*3.14*2 *4.3*I=18,360 V. I=340 A.

Temperature of solenoid with RF is Tsol=53^{o}C. Without RF but with solenoid at voltage Um=2.11 V, Tsol =35^{o}C. Active resistance of solenoid Rsol=0.15 Ohm. After switching off solenoid, current Tsol=32C. Power from solenoid current is $Um^2/Rsol$=29.7 W, and increases the solenoid water temperature by 3C. To increase Tsol by 28^{o}C, an average power of Psol=280 W is necessary, and pulsed power 4.7 kW. Pd=16-10-4.7=1.3 kW. For Faraday current Ifc=17 mA, the efficiency of current generation is λ=13 mA/kW at Um=2.11 V.

At <I>=0.872 V, Prf=34 kW. <I>ant =194.4 A. Pant=20 kW. Psol=5 kW. Pd=34-20-5=9 kW. Ifc=16 mA, λ=16/9=1.7 mA/kW at Um=0. At <I>=0.963 V, Prf=41.7 kW. <I>ant =250 A. Pant=34.3 kW. Psol=6 kW. Pd=41.7-34.3-6=1.4 kW. Ifc=25 mA, λ=25/1.4=17.8 mA/kW at Um=3.2 V.

Volume of the collar is 29 cm^3. Mass of the collar is 290 g. A specific thermal permeability of Mo is C=0.255 J/g K. Thermal permeability of collar is 75 J/c. A speed of the collar cooling after switching off the discharge is 0.7^{o}C/s. Power loss from the collar is 52 W (pulsed power 868 W from Prf=34.2 kW from RF generator at Um=1.68 V).



Cesiation: increase of Faraday cup current (mA) in time during cesiation from 3 mA to 13 mA at constant RF power 40% (10 kW in plasma, antenna, network and solenoid; blue max current, green-average current).

Forwarded RF power from RF generator is measured by directional coupler and calculated by formula:

Prf=45 x <I>^{2} kW, where <I> rms current in V.

Before discharge triggering all power is dissipated in antenna and matching network. For our case it is <I>=0.293 V, Prf=3860 W, antenna current <I>ant= 83.3 A, antenna voltage V=6,480 V.

At <I>=872 mV, Prf=34 kW. <I>ant =194.4 A. Pant=20 kW. Psol=5 kW. Pd=34-20-5=9 kW. Ifc=16 mA, λ=16/9=1.7 mA/kW at Um=0.

At <I>=963 mV, Prf=41.7 kW. <I>ant =250 A. Pant=30 kW. Psol=6 kW. Pd=41.7-30-6=5.7 kW. Ifc=25 mA, λ=25/5.7=4.4 mA/kW at Um=3.2 V.

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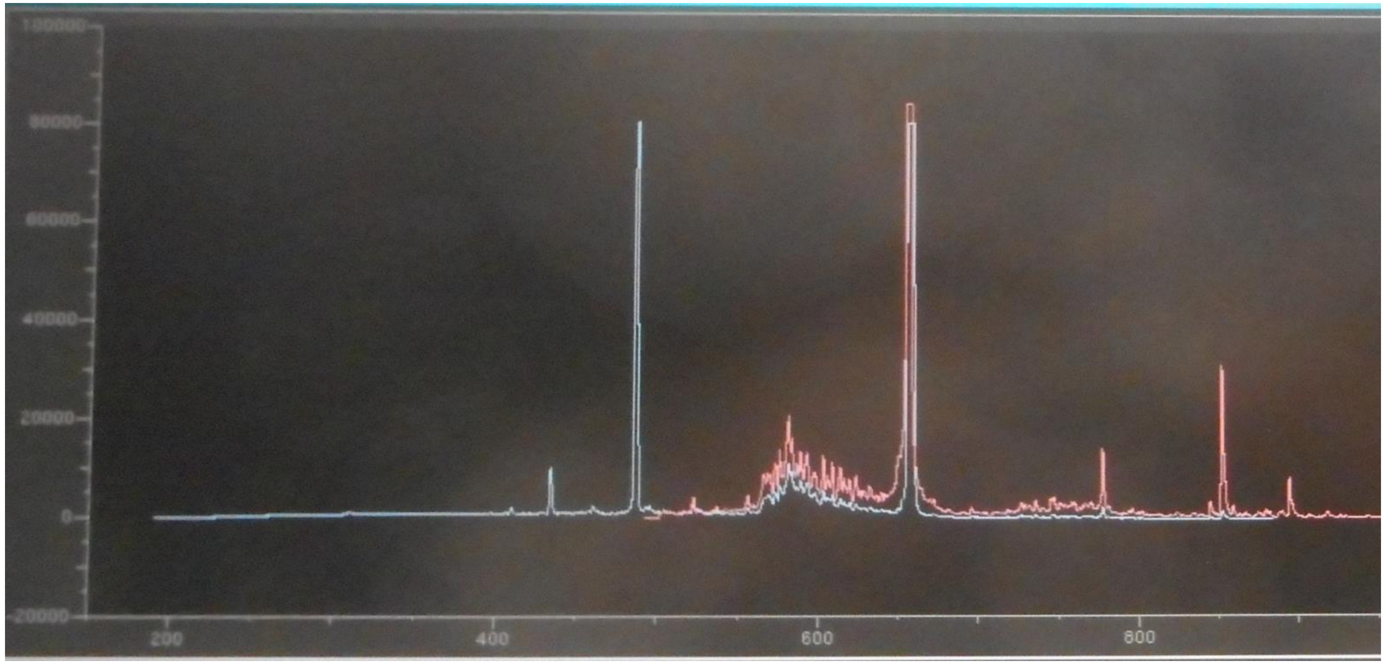
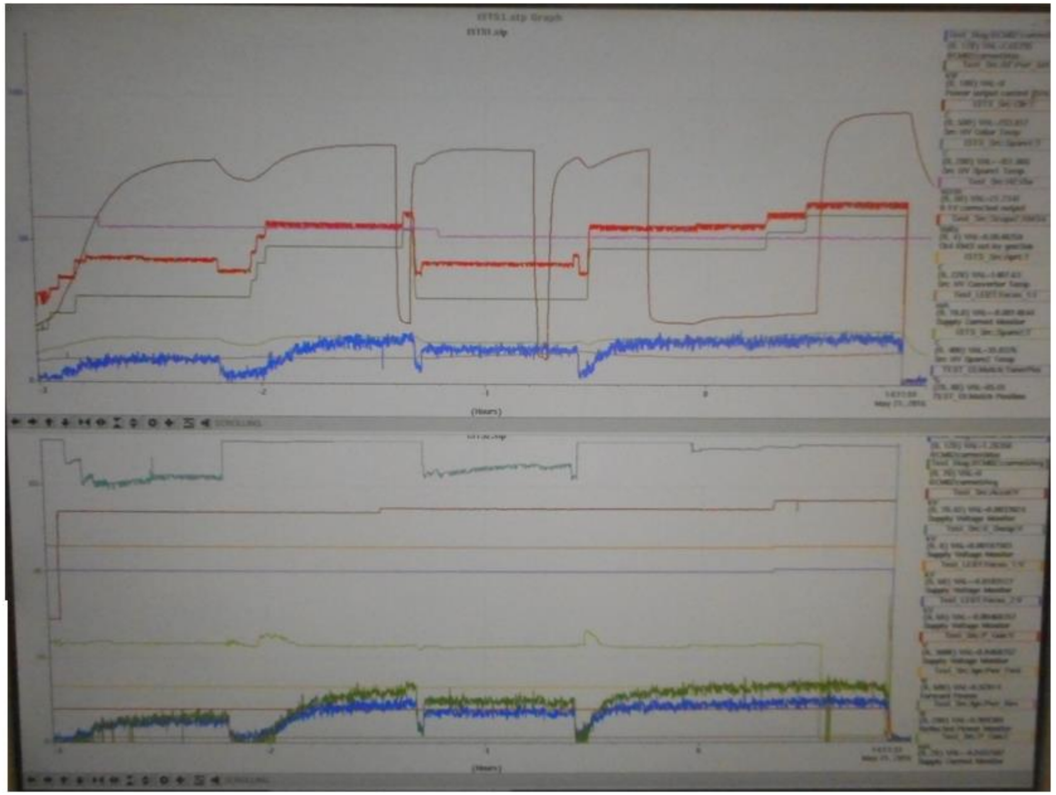
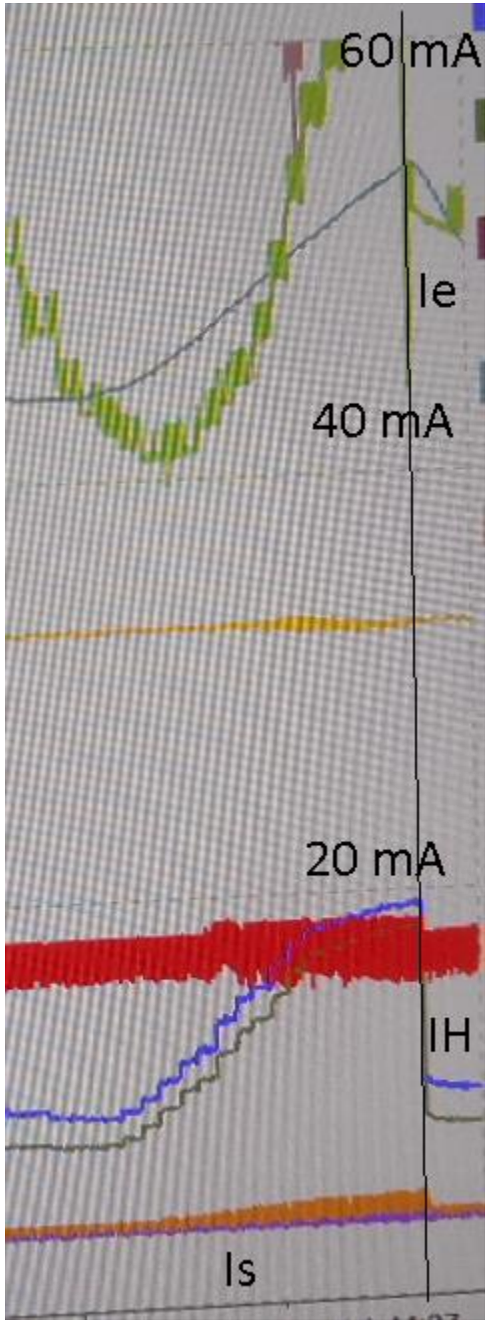
Optical spectrum of Hydrogen Discharge with cesium Lines 852 nm and 894 nm.

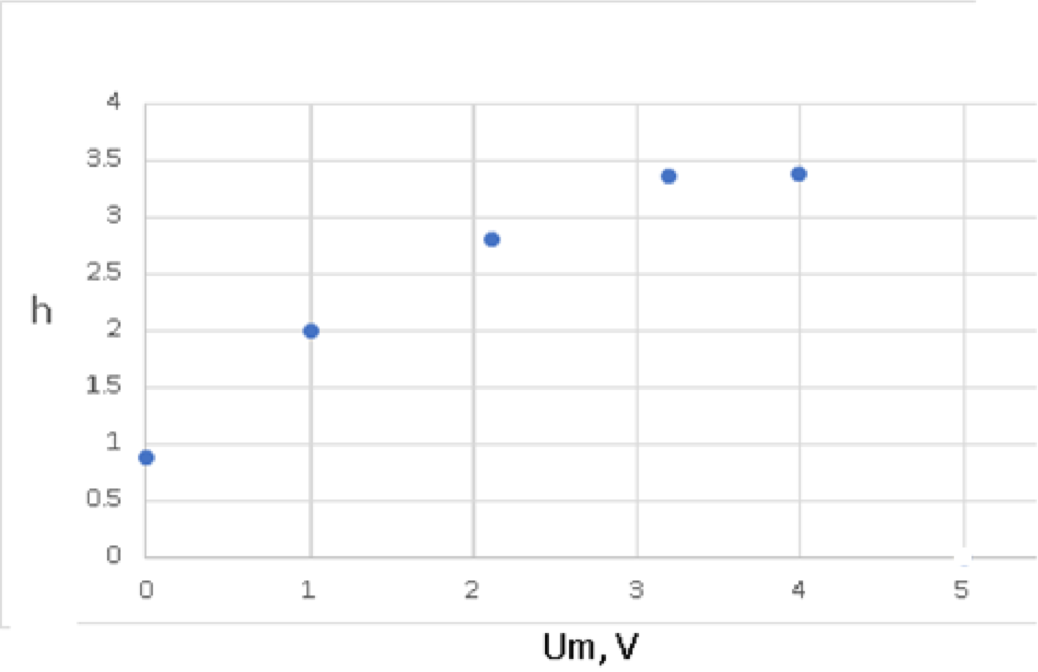




Change of collar temperature from 60C to 400C do not change efficiency of H- generation.



Dependences of I_e and I_{H-} on solenoid current, Is was variated during a time.
I_e is first decreases and then increases
I_{H-} is decreases, than increases



Dependence of efficiency h (mA/kW) of H- beam production on solenoid voltage with a pulsed 2 MHz RF power.

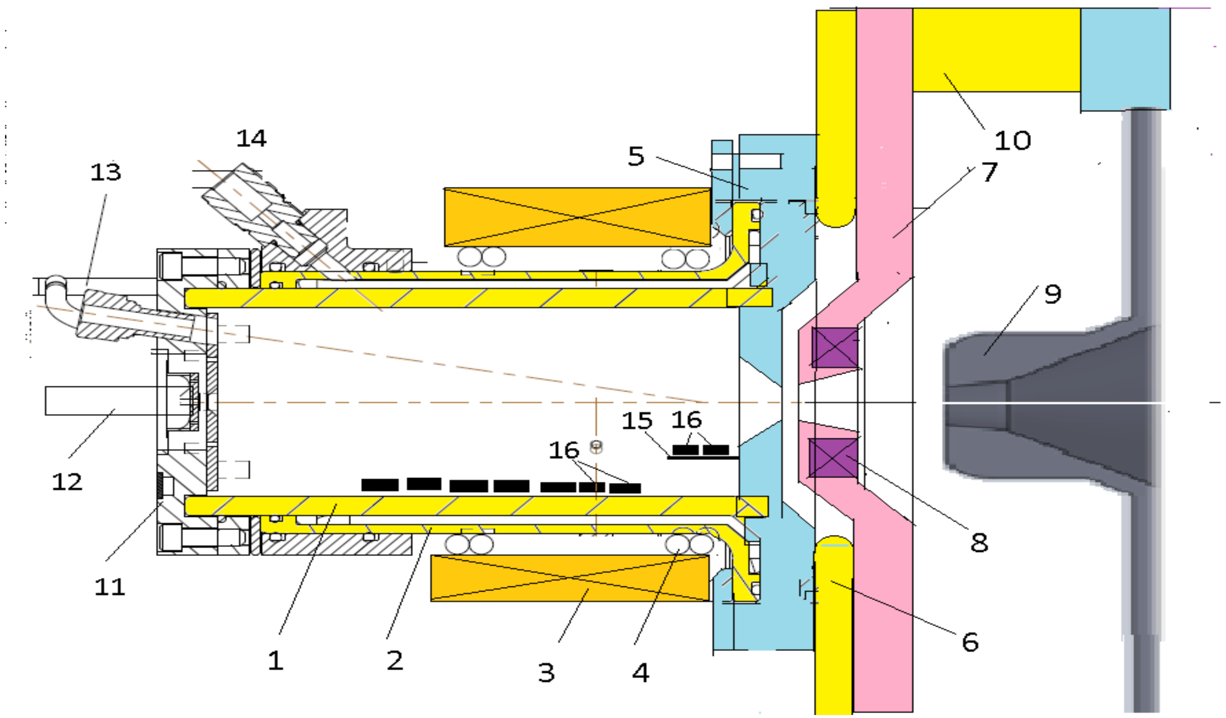
CW operation of the SA SPS with negative ion extraction was tested with RF power up to ~2 kW from the generator (~ 1.5 kW in the plasma) with production up to Ic=10 mA. Long term operation was tested with 1.8 kW from the RF generator (~1.3 kW in the plasma and 0.5 kW is dissipated in the antenna and matching network) with production of Ic=9 mA, Iex ~15 mA (Uex=8 kV, Uc=15 kV). This mode of operation was tested during : 50 days. After this test SA SPS was capable to work.

The collector current is increase with increase of a magnetic field up to Um ~4 V, and decrease with further increase of magnetic field because a plasma flux is compressed to the emission aperture and interaction of plasma flux with a collar surface is decreases.

The specific power efficiency of negative ion beam production in CW mode is up to Spe = 20 mA/cm^2 kW. (In the existing RF SPS the Spe ~ 4-6 mA/cm^2 kW; in the TRUIMF filament arc discharge negative ion source the best Spe is about 2 mA/cm^2 kW; in a compact Penning discharge SPS the Spe is 150 mA/cm^2 kW).

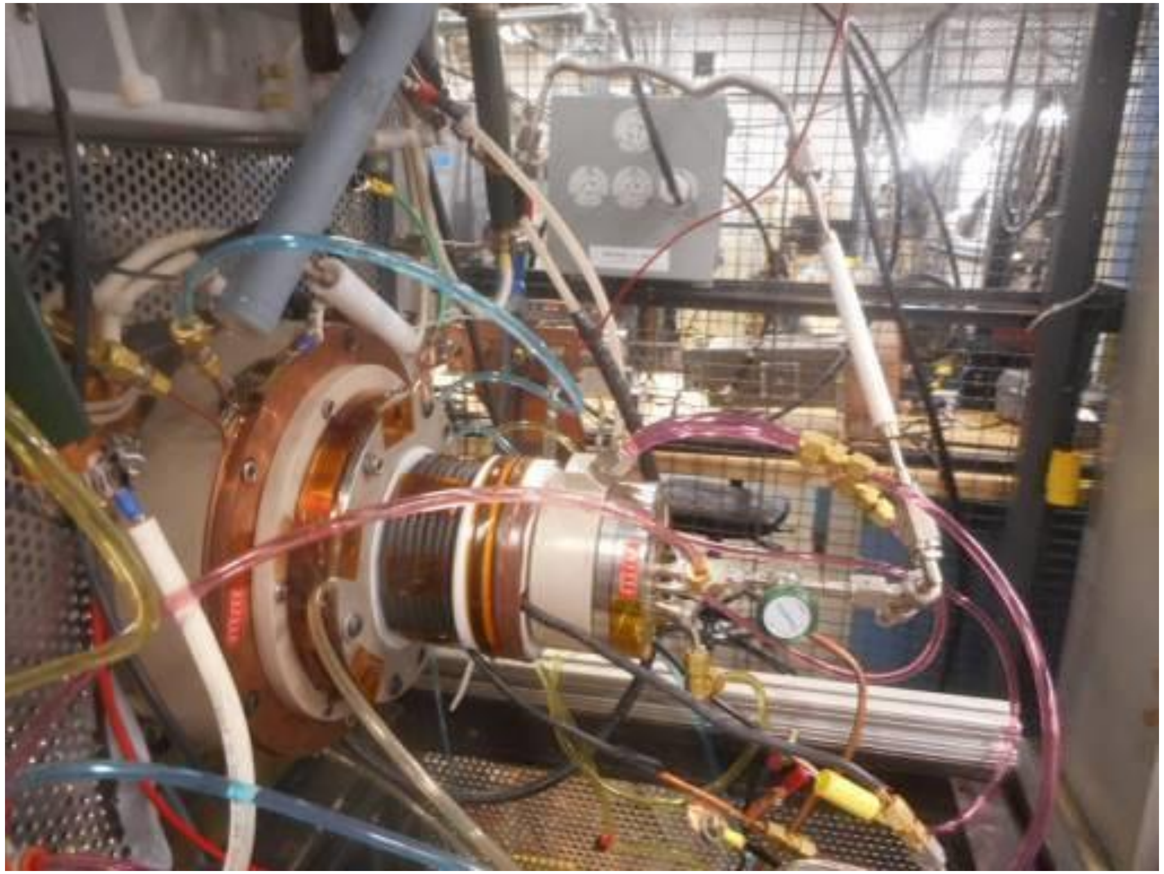
CW RF discharge can be triggered with CW discharge in the Triggering Plasma Gun (TPG) at gas flow Q~8 sccm and can be supported up to Q~3 sccm. The main CW discharge in SA RF SPS can be triggered without discharge in the TPG at Q~ 10 sccm and supported up to Q~4 sccm.

Schematic of helicon discharge LV SPS

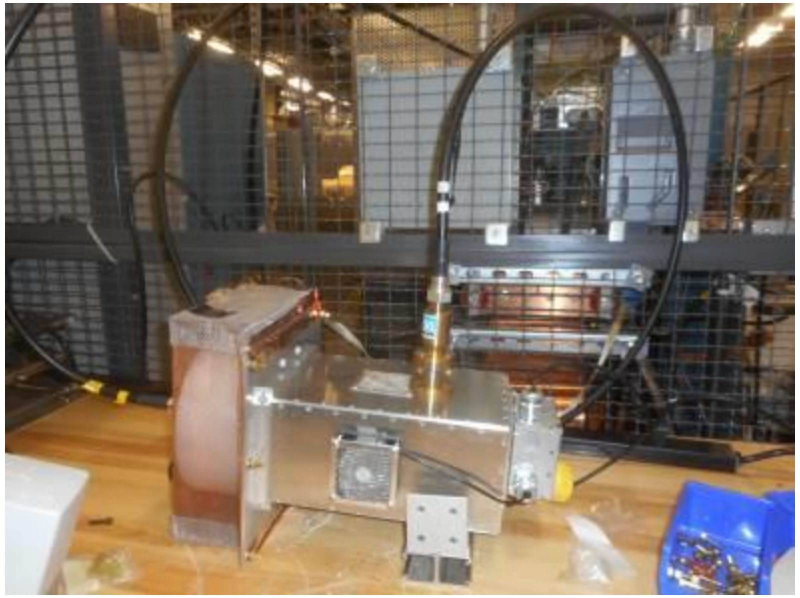


1-Gas discharge chamber (AlN),
2- cooling jacket from keep,
3- solenoid, 4- helicon antenna,
5-plasma electrode with conical collar and emission aperture,
6-extractor insulator, 7- extraction electrode, 8-permanent magnets,
9-grounded electrode,
10- insulator, 11- back flange,
12- gas inlet, 13- view port,
14- cooling water inlet-outlet,
15-. shelf, 16- pellets.

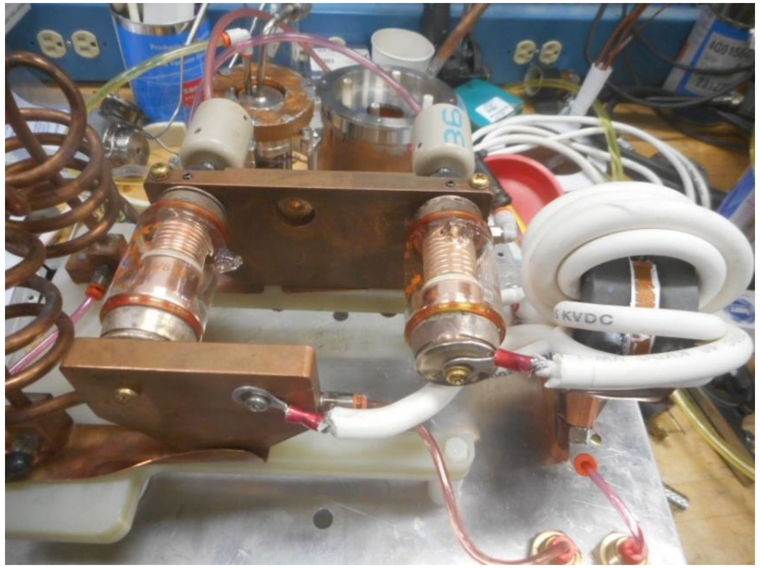
Compact design of RF SPS with solenoidal magnetic field



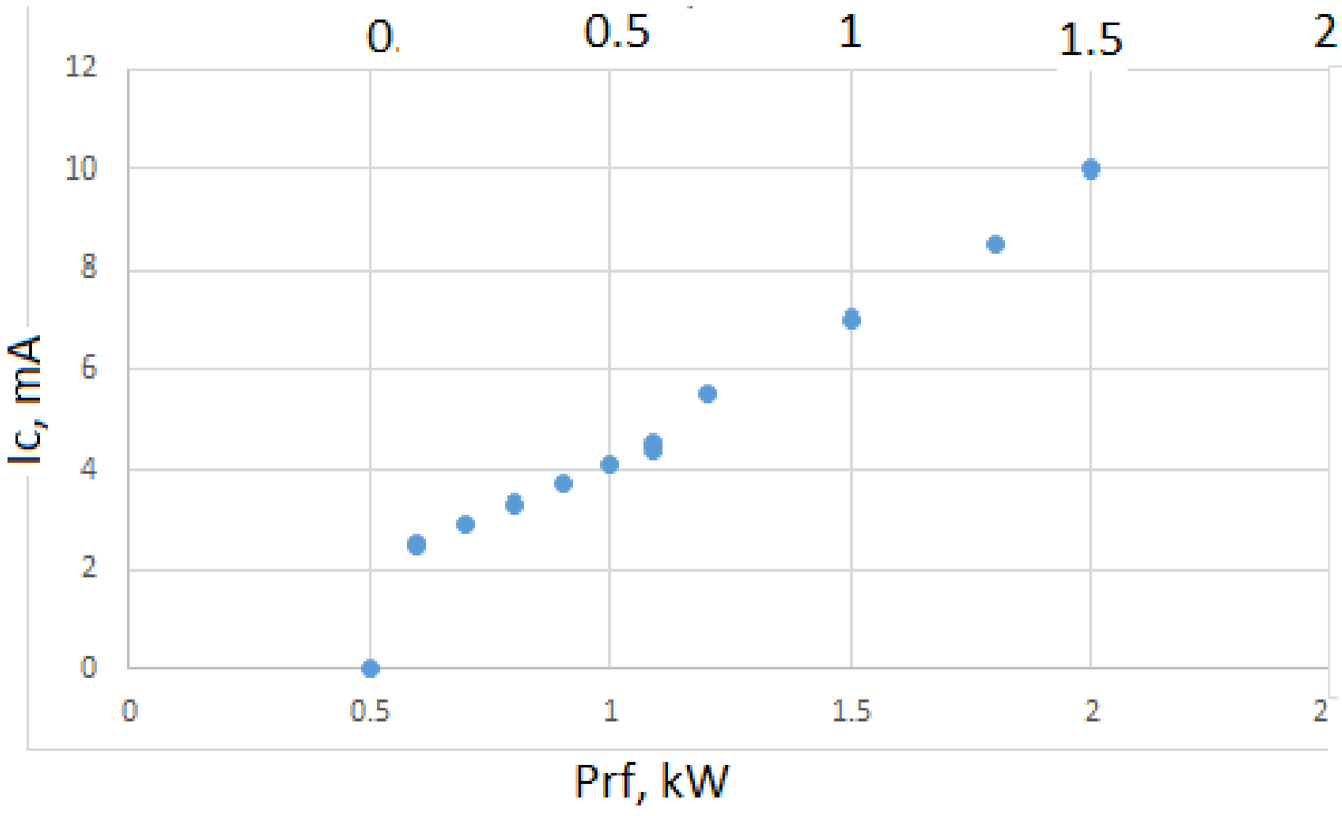
Insulating transformer

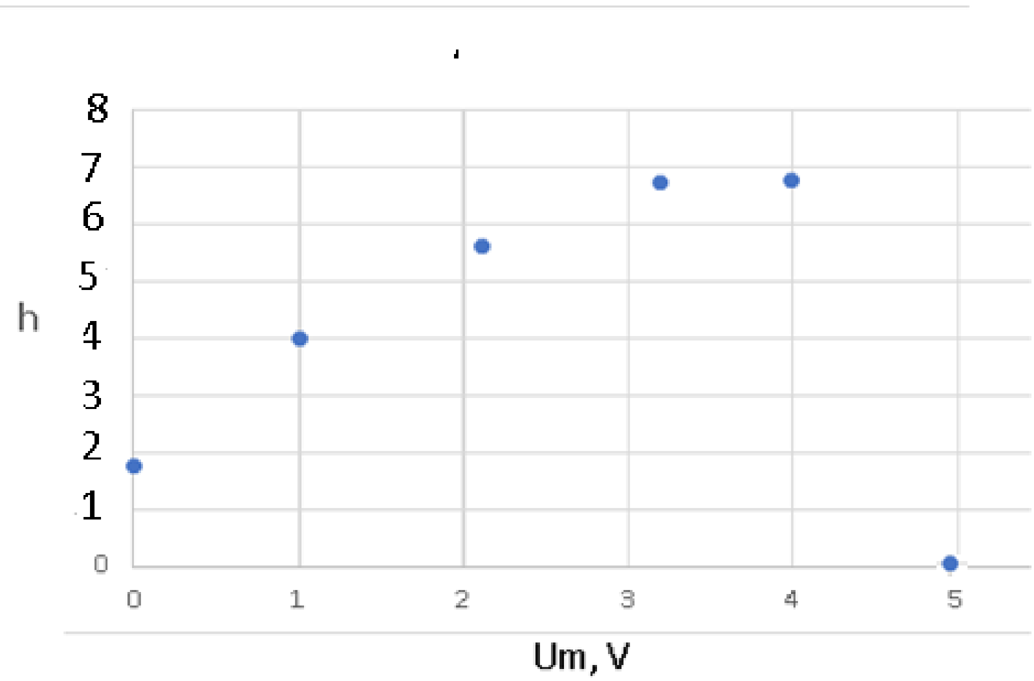


Matching network



CW operation. Dependence of collector current I_{fc} on RF power from RF generator and from discharge power in plasma (upper scale).





Efficiency of H- generation on solenoid voltage