Inductively Driven Surface-Plasma Negative Ion Source for N-NBI use

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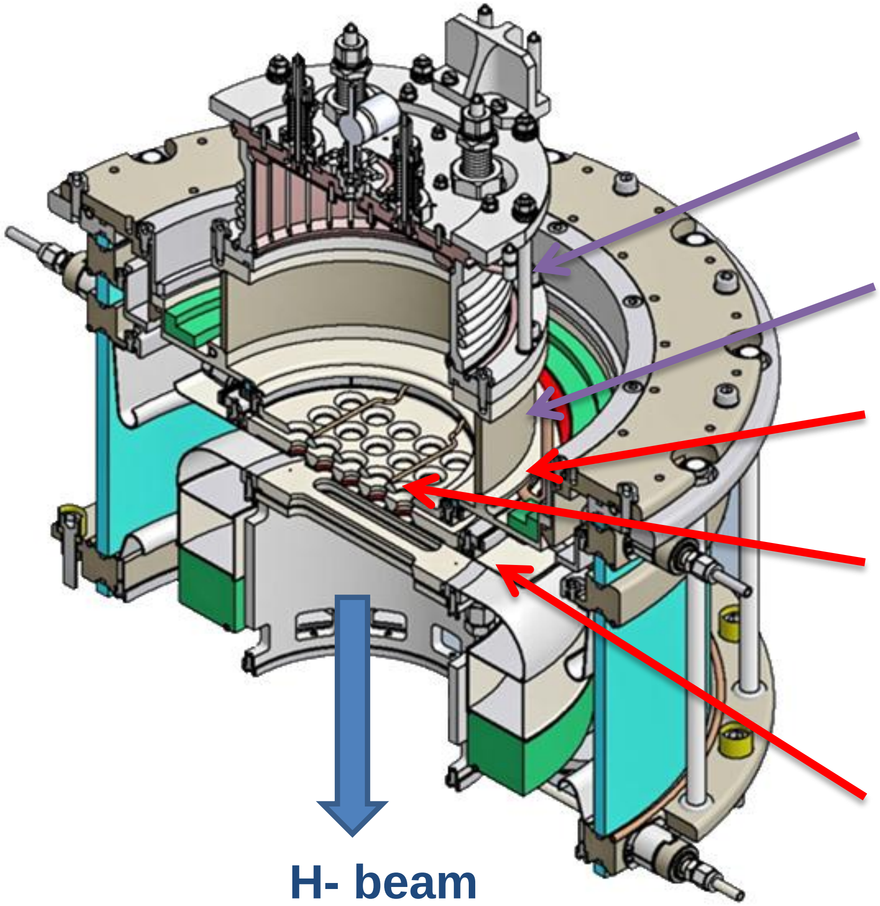
OUTLINE

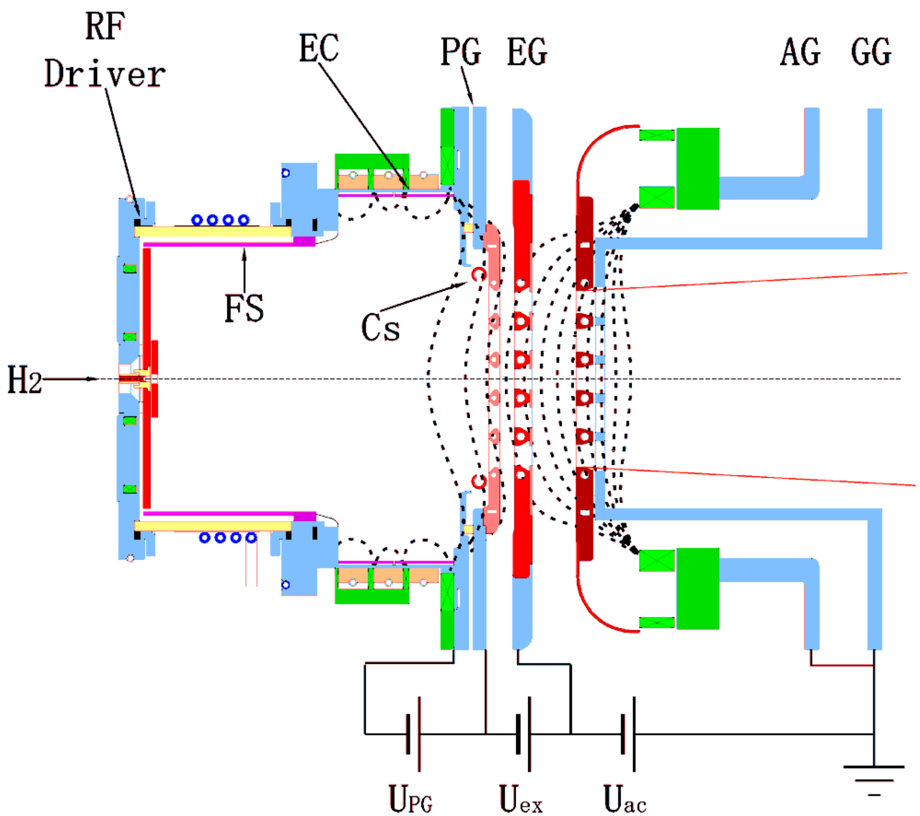
- BINP source design
- Negative ion beam production
- Persistent work with a single cesium seed
- High Voltage holding improvement

General scheme of inductive RF source

Negative Ions are produced by conversion of plasma particles on the cesiated PG surface (Surface-Plasma Source)

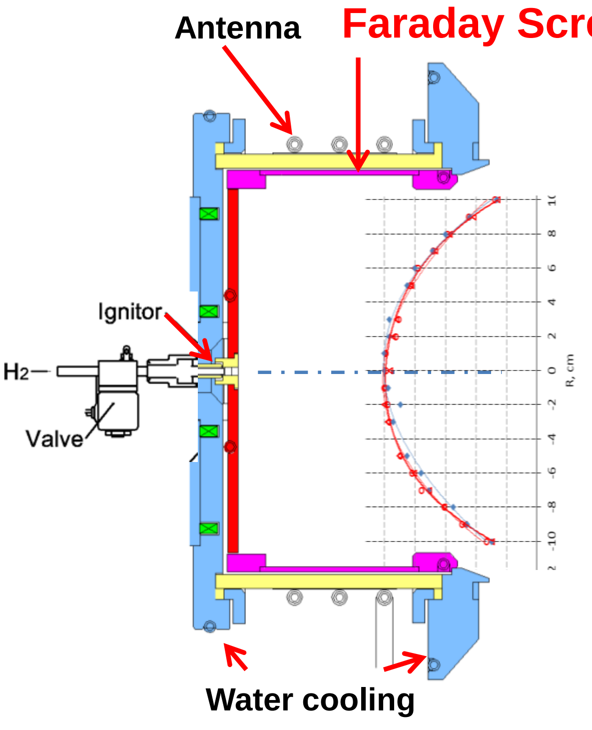


What's new in the BINP source

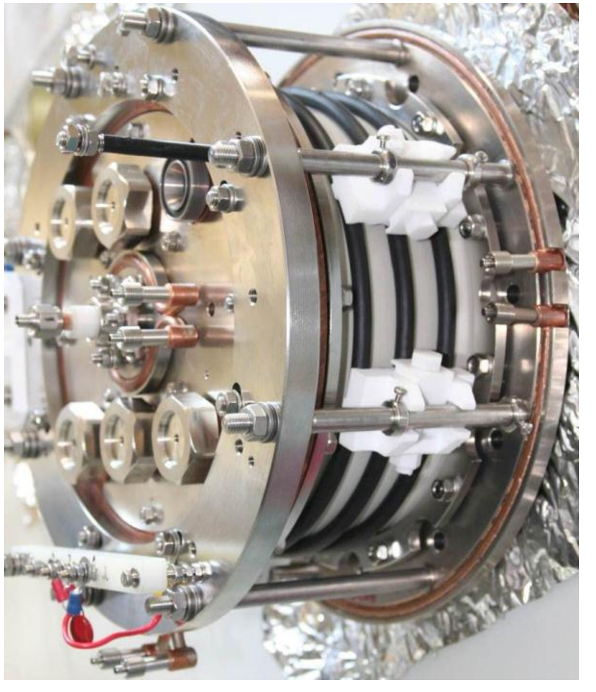


1. Active temperature control of extraction and plasma grids **(heating/cooling by hot fluid)**
2. Cesium seed to PG periphery
3. Concaved magnetic field in the IOS gaps

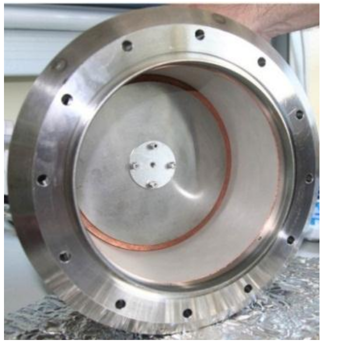
RF driver



Frequency 4 MHz
Antenna – 3-4 turns
PI flux ~ 0.3-0.5 A/cm^2



Driver with AlN ceramic

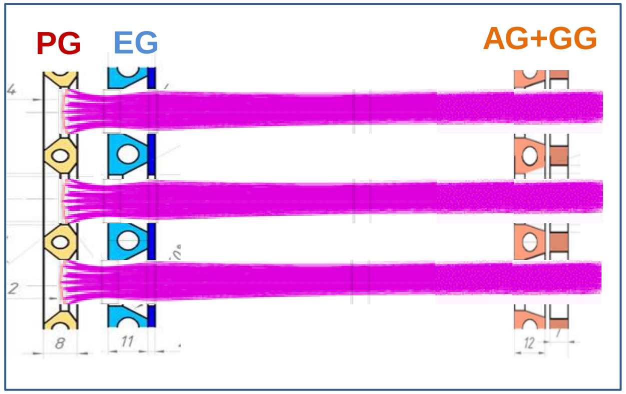


Driver **without FS**

Molybdenum FS with slots

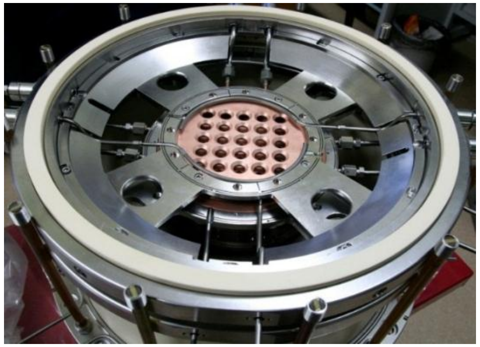
Plasma potential in RF driver is high (~60 V)
It is ~ 7-10 V lower in the driver without FS

Ion Optical System

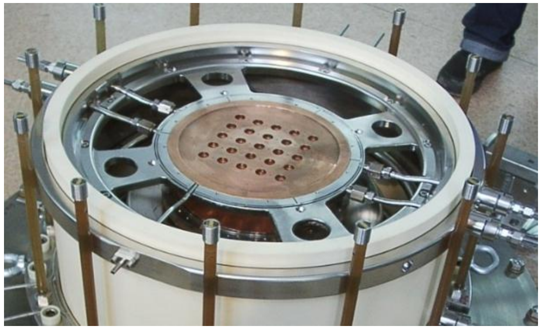


IOS electrodes geometry

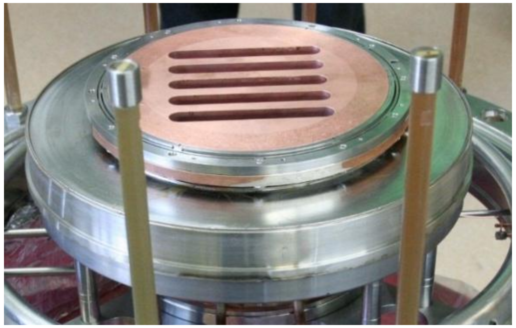
Emission apertures	21 x Ø 1.6 cm =42 cm^2
Emission area	Ø 14 cm = 220 cm^2
Extraction voltage /gap	12 kV / 5 mm
Acceleration voltage/gap	108 kV/ 49 mm
IOS length	75 mm
Transverse magnetic field	12-18 mT



Plasma Grid
with 21 apertures



Extraction Grid
with 25 apertures



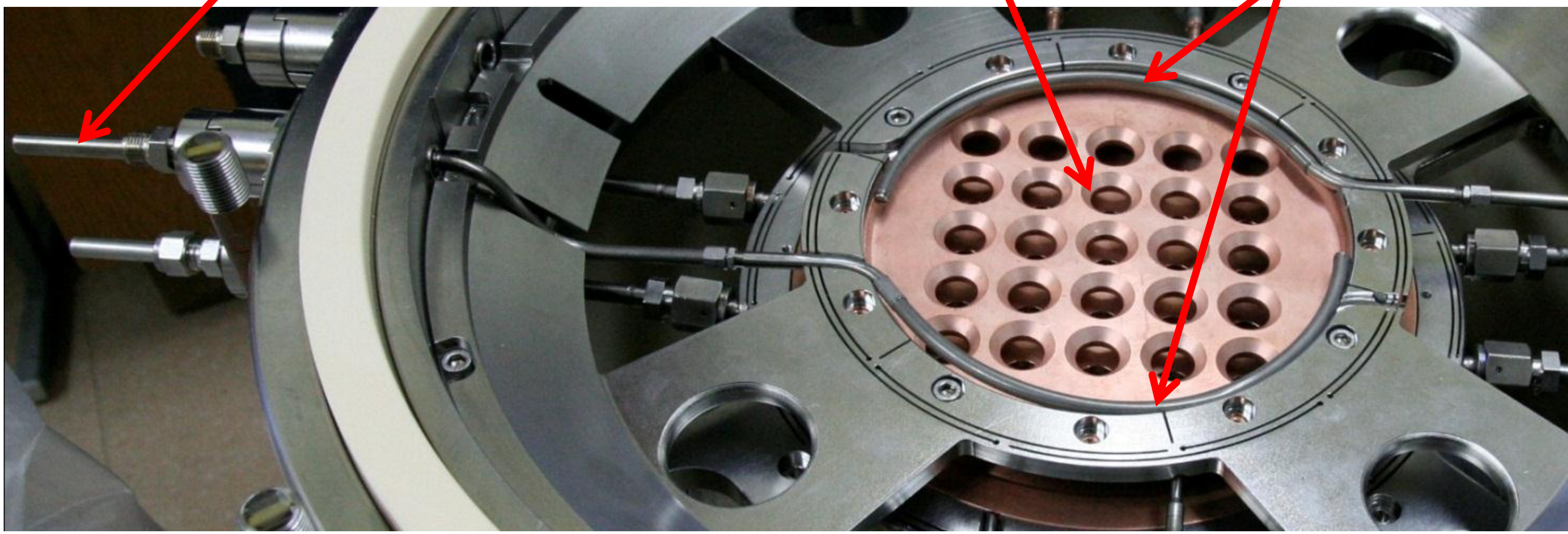
Acceleration Grid
with 5 slits

Distributed Cesium Seed

Connection to oven

Plasma Grid

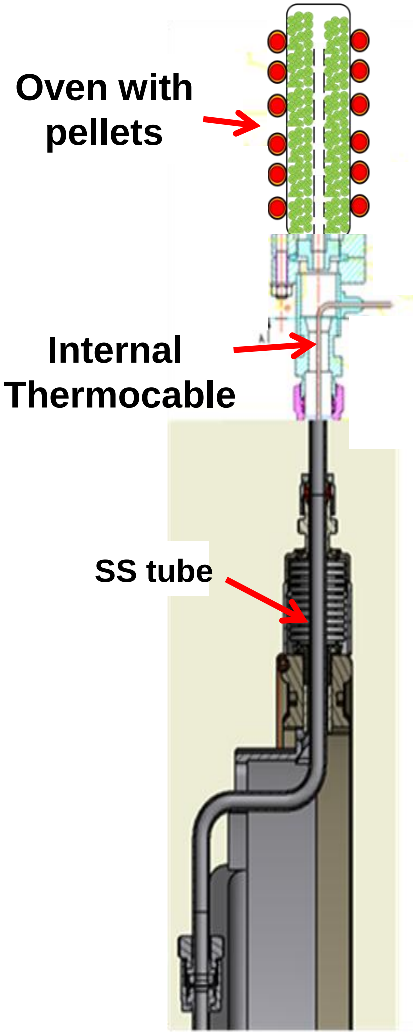
Distribution Tubes with openings



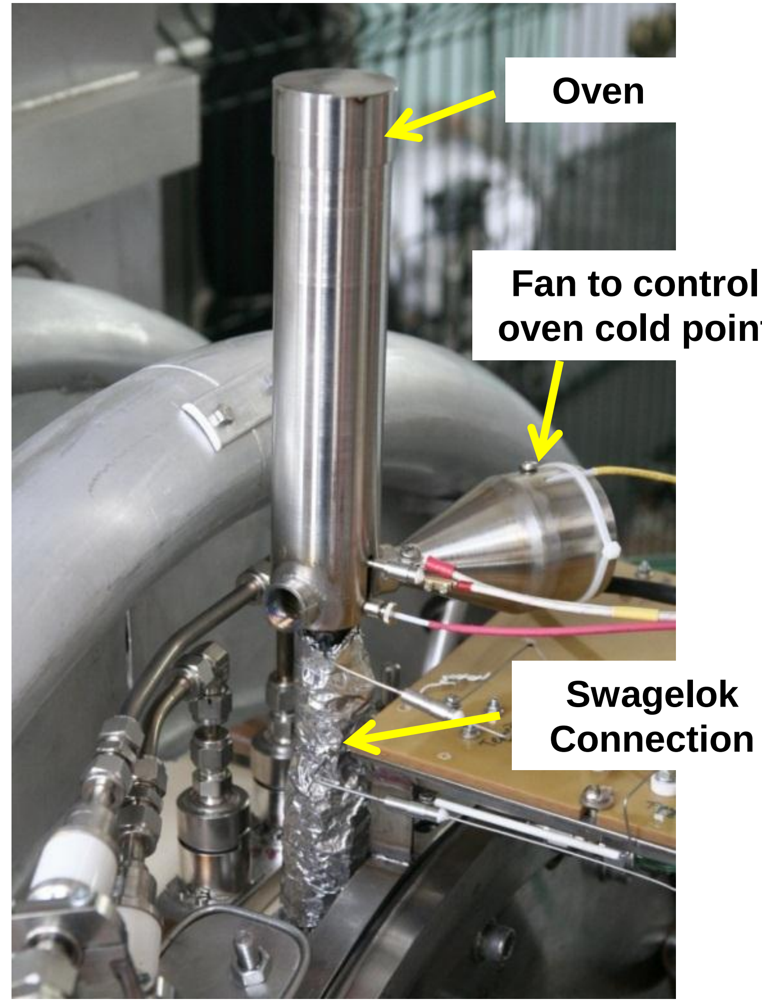
Plasma Grid with Cesium Distribution Tubes

- **Distribution tubes have ø 0.3 mm openings, drilled with 10 mm pitch.**
- **Tubes are heated to temperature ~250 ^{o}C by internal thermocable.**

Cesium systems with pellets

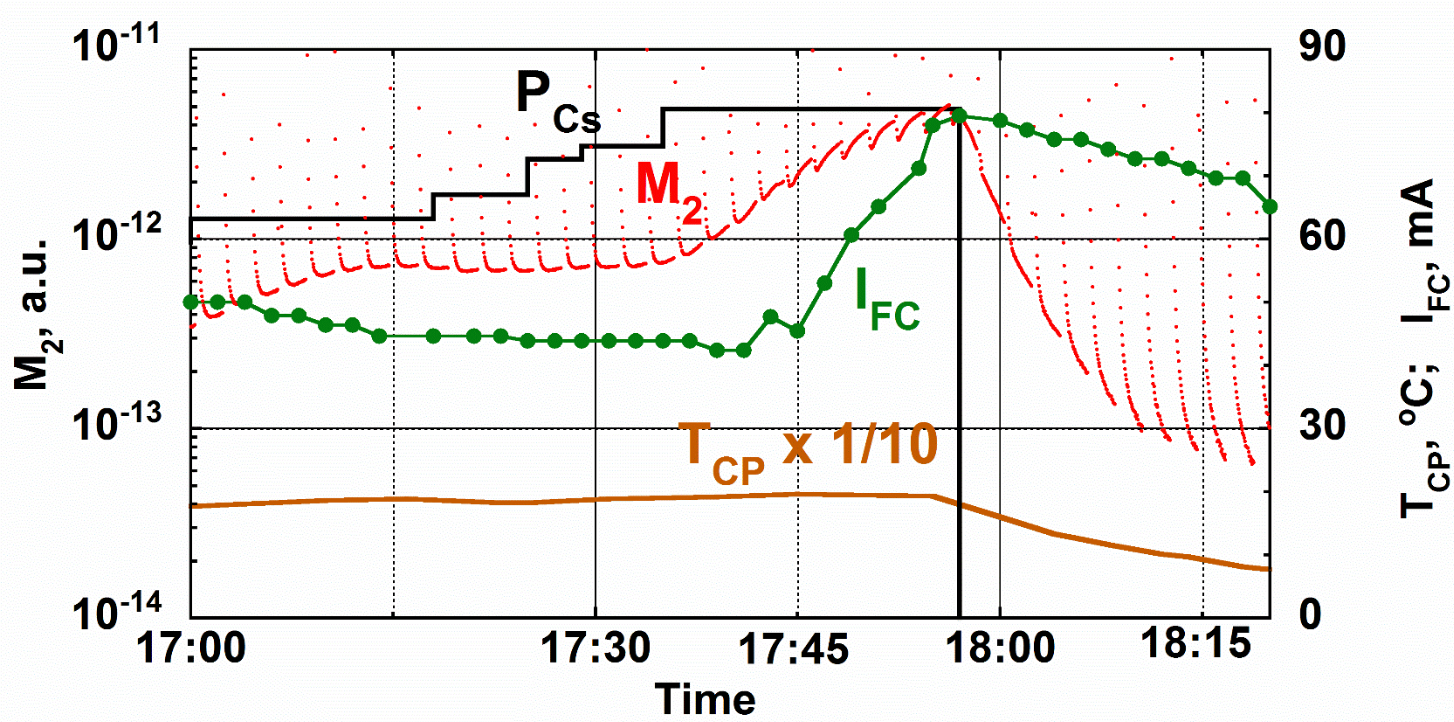


Cs system scheme



Cs Oven at the top of PG flange

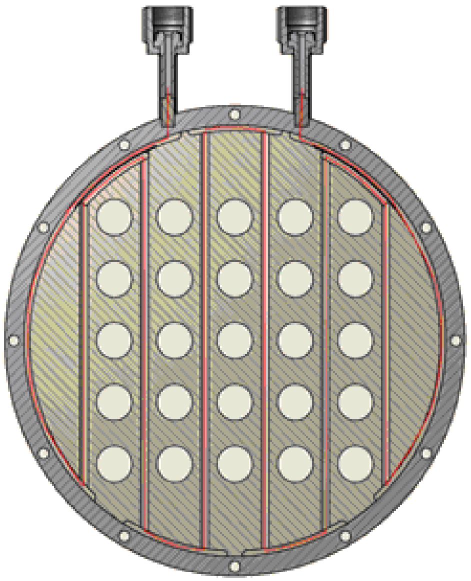
Procedure of Cesium Deposition



Cesium deposition during the beam shooting

P_{Cs} – gradual increase of oven heating ~ 1hour.
Oven "cold point" kept at 180 °C to accumulate cesium
M_2 - Hydrogen partial pressure. Spikes - beam shots, base line - pellets outgassing.
H- beam current increased 2 times with the cesium release

Thermal Stabilization of Electrodes

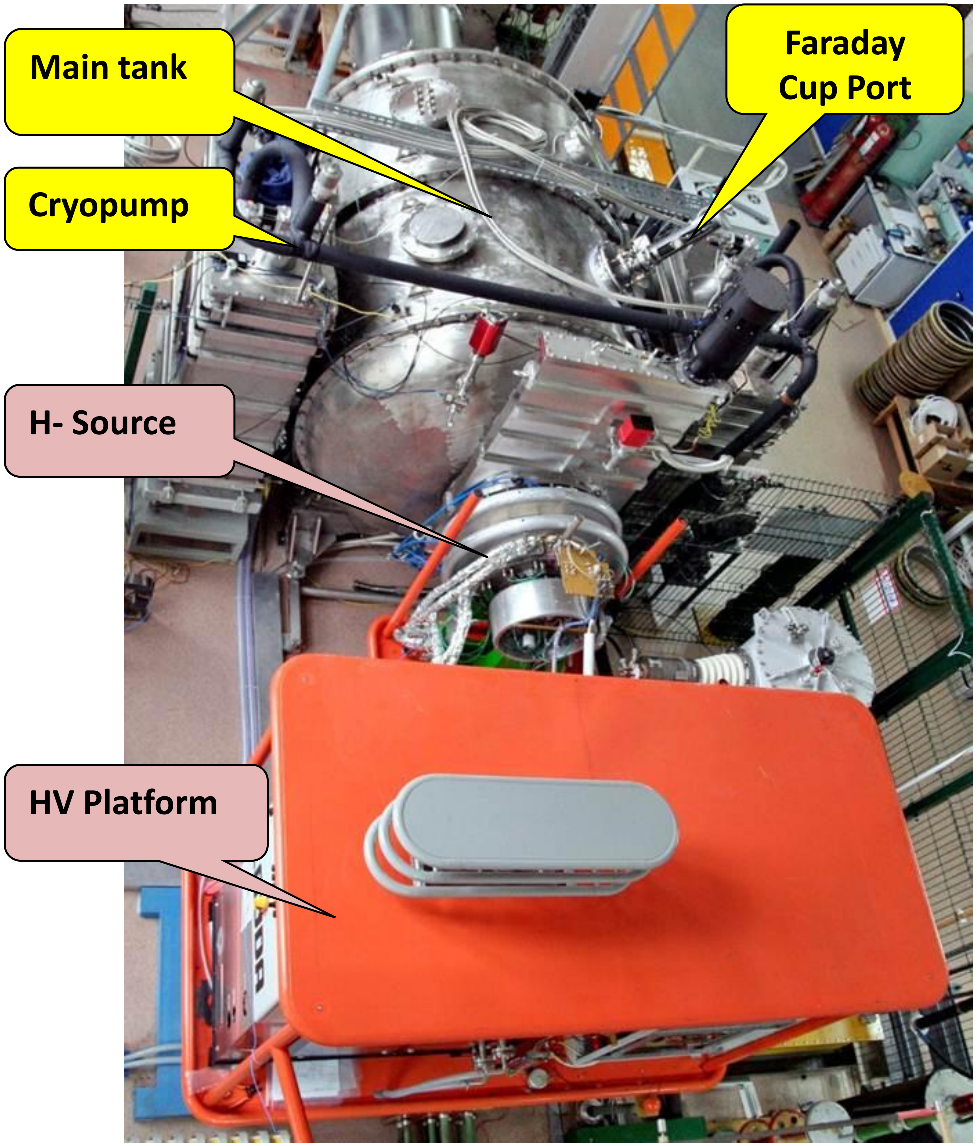


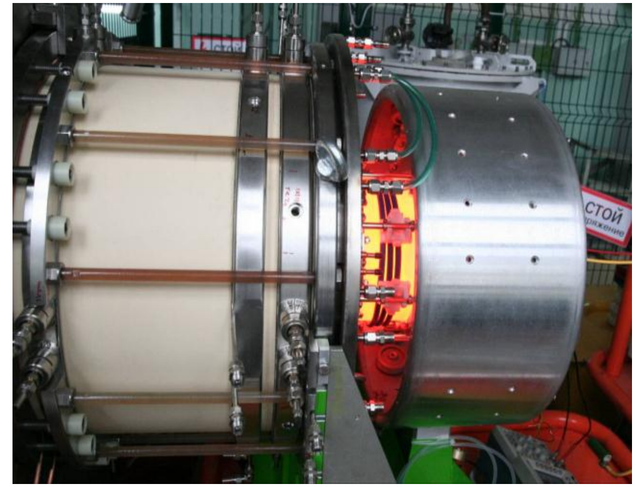
PG channels scheme

Thermal Stabilization System LAUDA at 120 kV platform

- Plasma Grid and Extraction Grid are heated/ cooled by circulation of heat transfer career (Marlotherm) through the electrodes channels
- it provides an active temperature control, independent of discharge power

Test stand

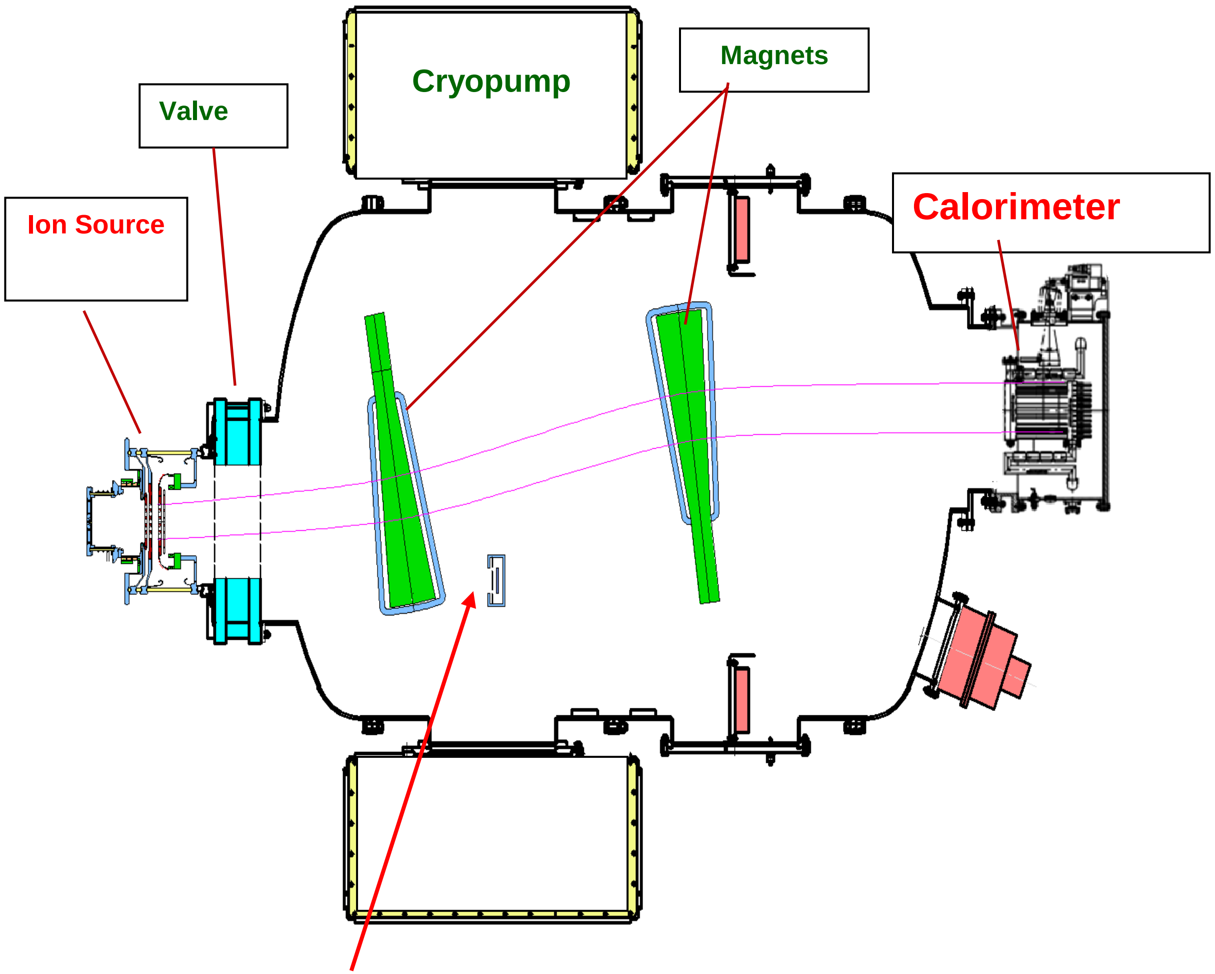




- Ion Source, Thermo-stabilization system and power supplies racks are at 120 kV platform

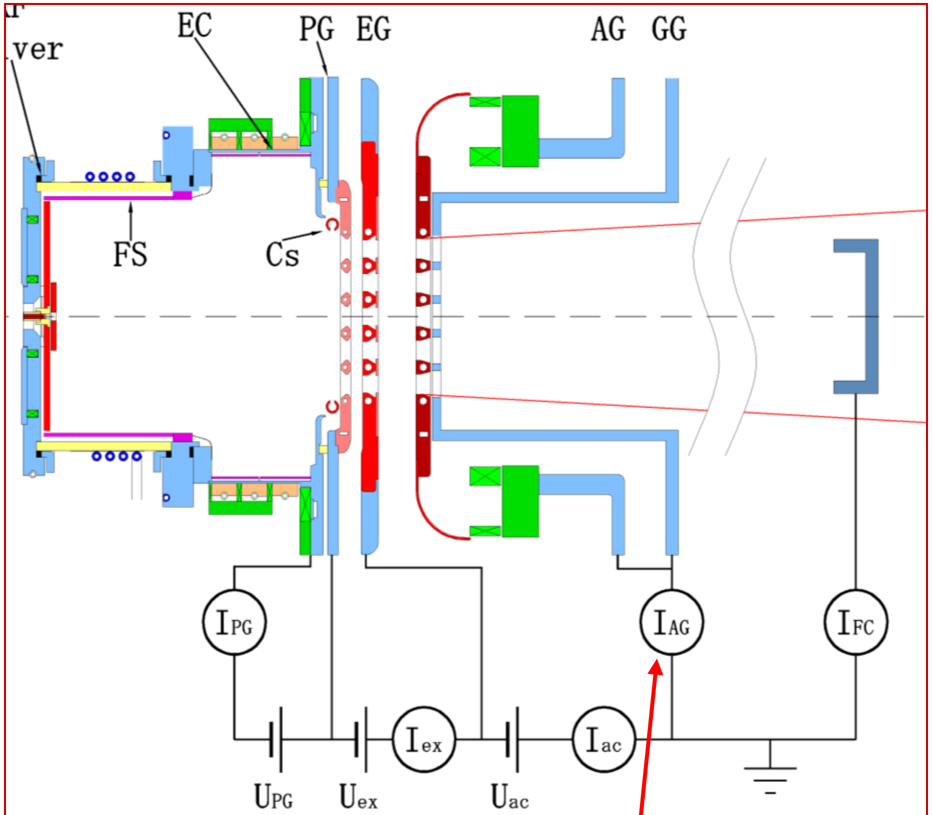
- 10 m^3 vacuum tank with two cryopumps (~200 m^3/s for H_2)

Beam current measurements



- Faraday Cup current (1.6 m from the IOS)
- By calorimeter (4 m from the source)

IOS currents measurements



Acceleration Grid current I_{AG} consists of ions and **secondary electrons**, deflected to AG and GG by the transverse magnetic field

I_{AG} is about ~ 30-40 % of total current I_{ac}

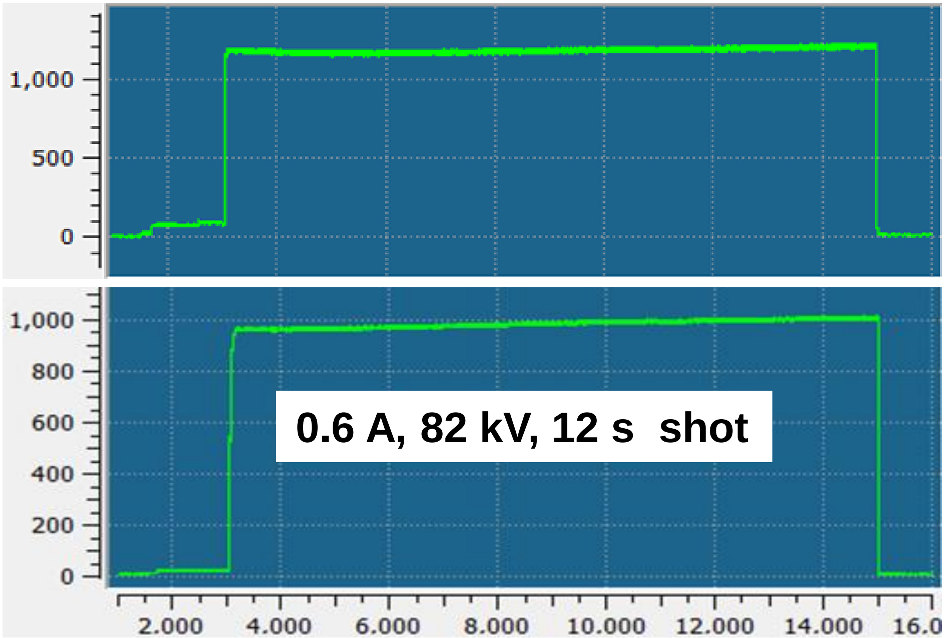
Beam at IOS exit $I_b = I_{ac} – I_{AG}$ consists mainly of H^- ions

Differential current $I_e \leq I_{ex} – I_{beam}$

includes the electrons and H- ions, intercepted by EG and AG.

At optimal perveance it consists mainly of electrons.

FC and IOS currents Oscillograms

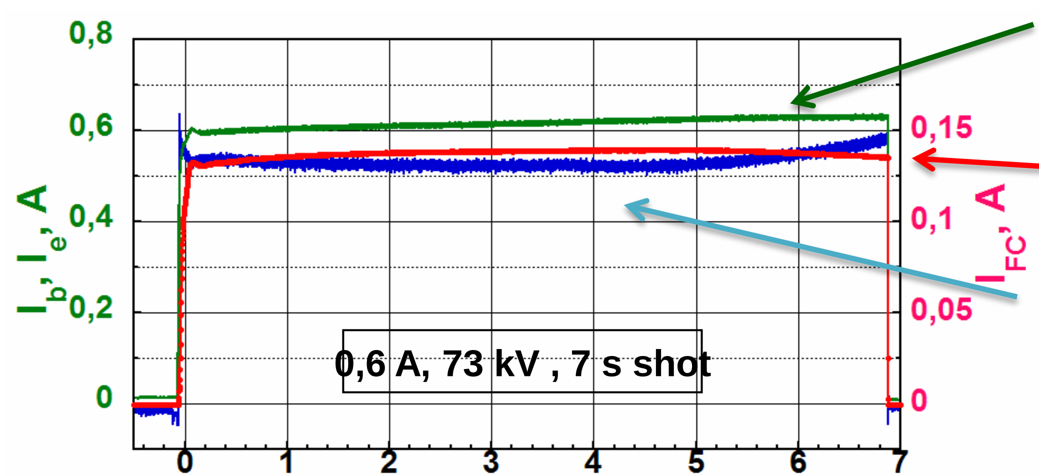


Total extracted current

I_{ex} = 1.1 A

Acceleration circuit current

I_{ac} ~ 0.9 A



Beam current at IOS exit

$I_b \approx I_{ac} - I_{AG} \approx 0.6$ A

Faraday cup ø 10 cm

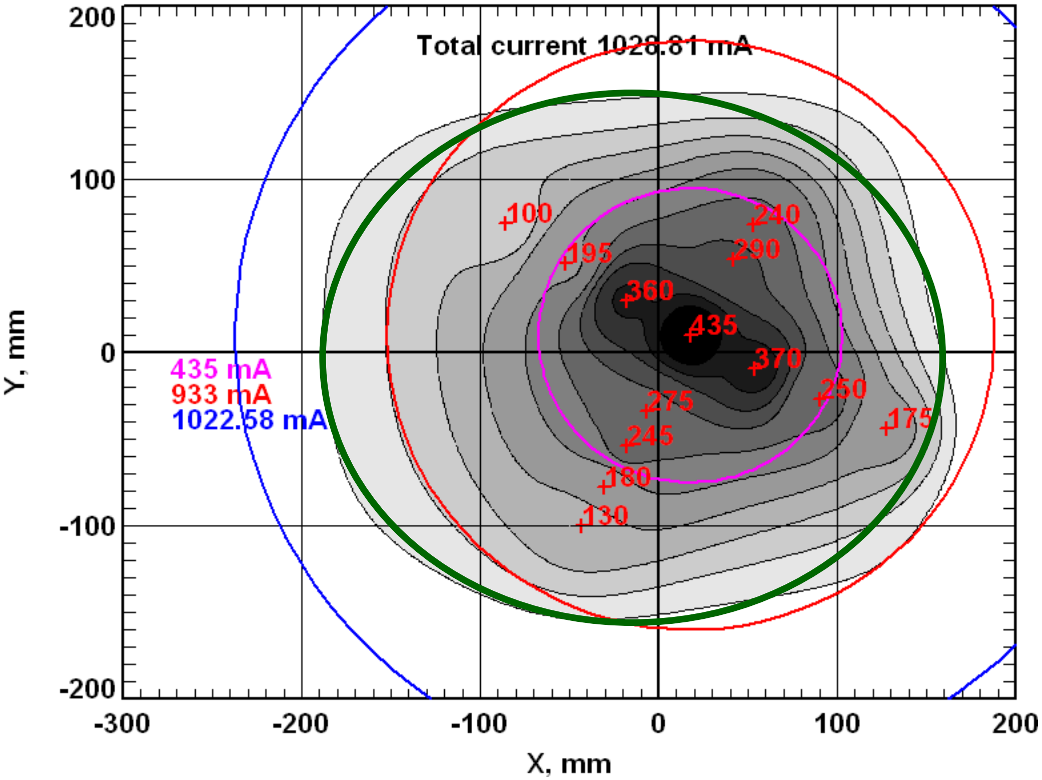
I_{FC} ~ ¼ I_b

Co-extracted electrons

$I_e \leq I_{ex} - I_{beam}$ ~ 0.5 A

electrons / ions I_e / I_{H-} = ~ 1

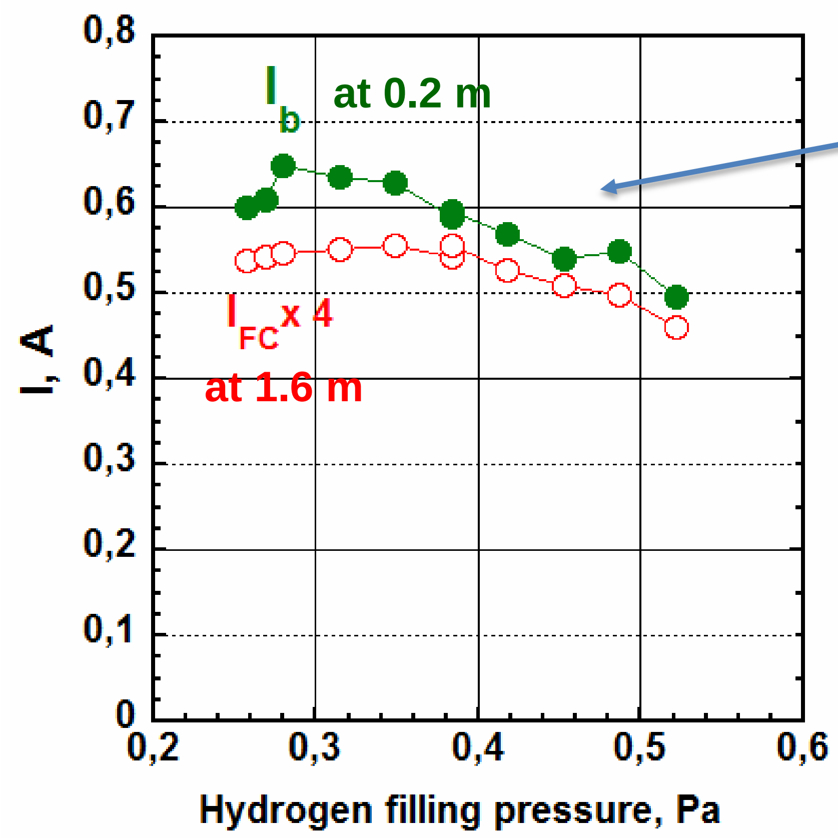
Beam Current distribution, measured by FC scan



Cross section of the beam for 80 kV, 30 kW shots, FC scan during 1.5 hrs run at nominal parameters.
Crosses indicate the FC positions,
digits - the current at this point.
FC input aperture 17 cm

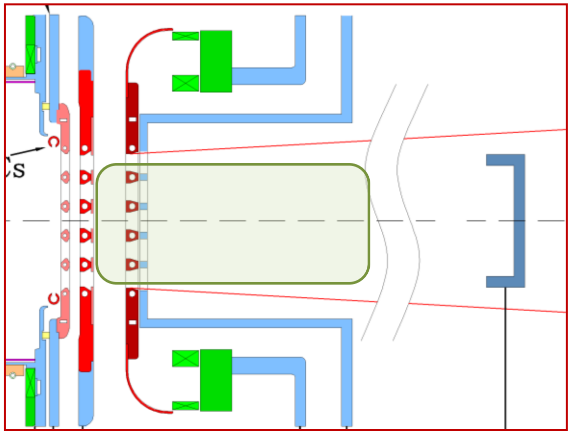
- **Faraday cup ø 17 cm**
  Maximal FC current ~ 0.43 A
  Integral H- beam current 1 A.
- **90% of the beam (green ellipse) has the sizes ~34 x 30 cm**
- **Beam divergence ± 63 x ± 50 mRad**
- **Beam at IOS exit I_b = 1.2 A (15% higher, than Integral beam at FC 1A)**

Comparison of outgoing beam current and Faraday Cup current

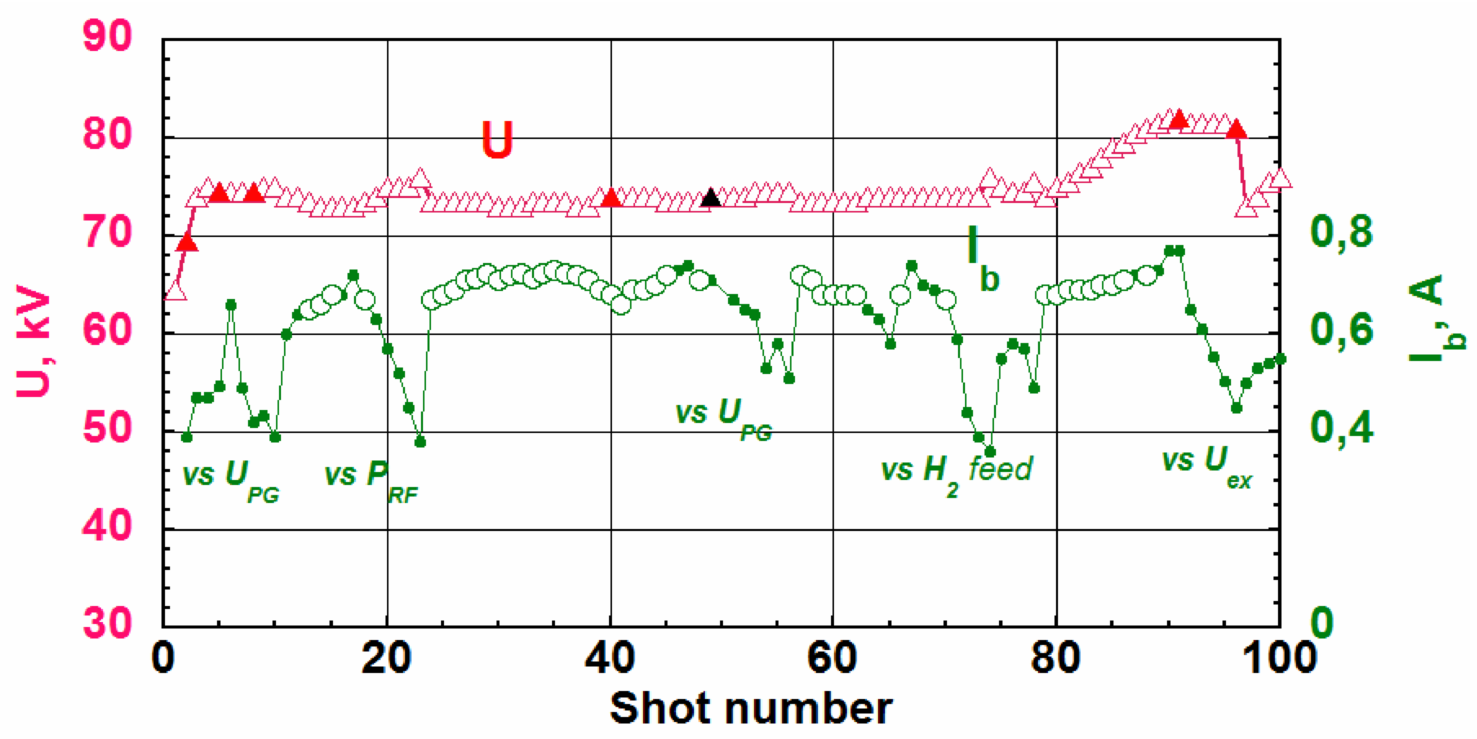


Beam current I_b and Faraday cup current I_{FC} vs H_2 filling pressure

The similar decrement of I_b and I_{FC} vs H_2 shows **the dominant stripping of H- ions** in the AG+GG area .



Reliability and persistence



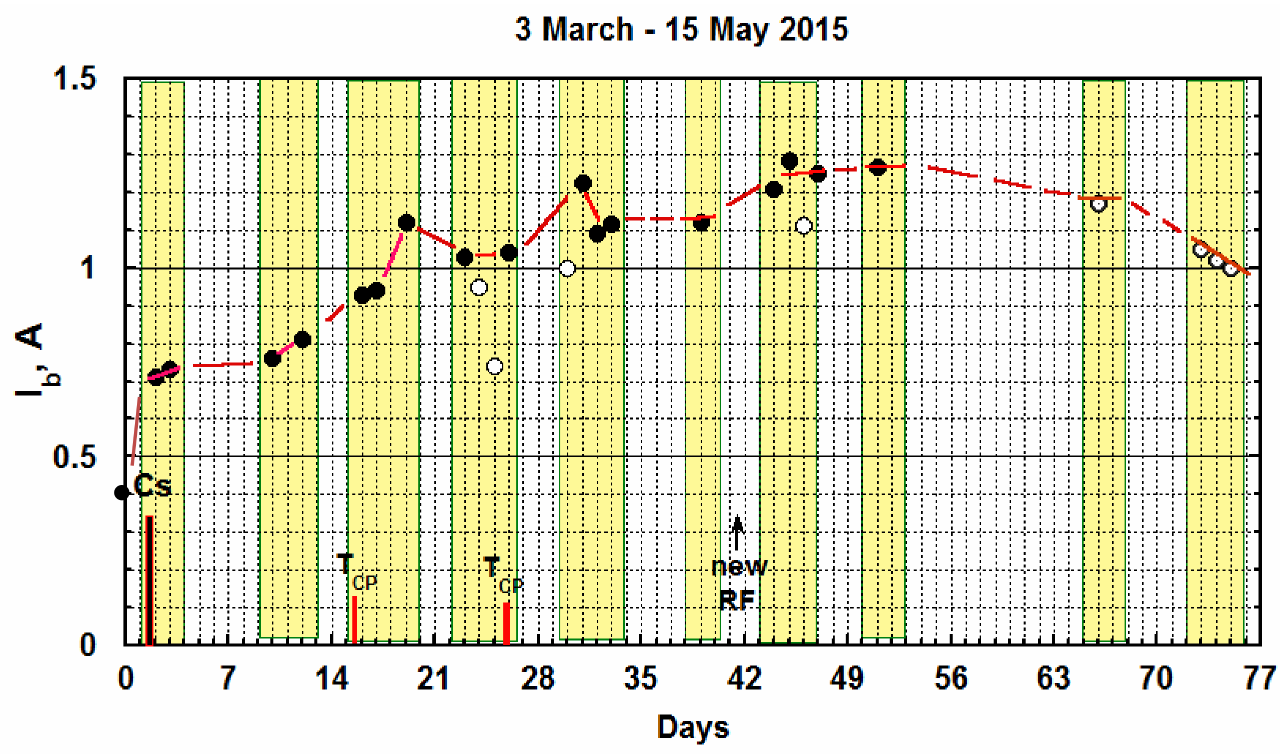
High Voltage and Beam current persistence during the experimental run

7 BD during 100 shots even under the IOS stressing by deviation of the source parameters.

H- beam with the stable nominal current (0.7 A for this run) is produced

at the source nominal parameters

Long- life Cesium Effect



Beam current Evolution after the single cesium seed.

Solid circles – at nominal parameters, empty – at shifted parameters

The weekend and vacations pauses are shown by white spaces.

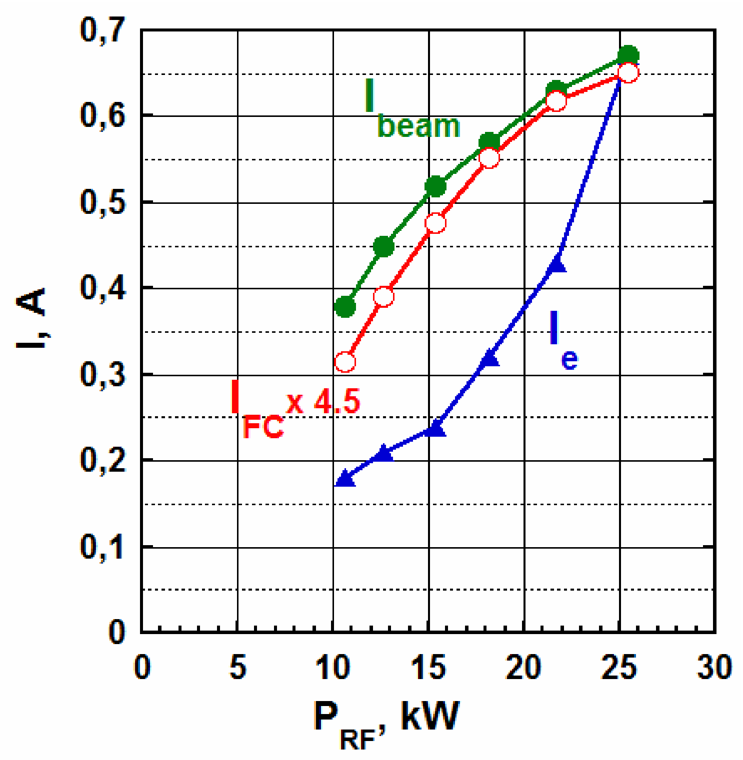
The single oven heating (~ 0.5 G Cs release) increases H-beam to 0.7 A.

Two cesium additions were done by the oven cold point heating on 14 and 26 day.

>1 A beam was sustained during 2 month

Beam and electron current Dependencies

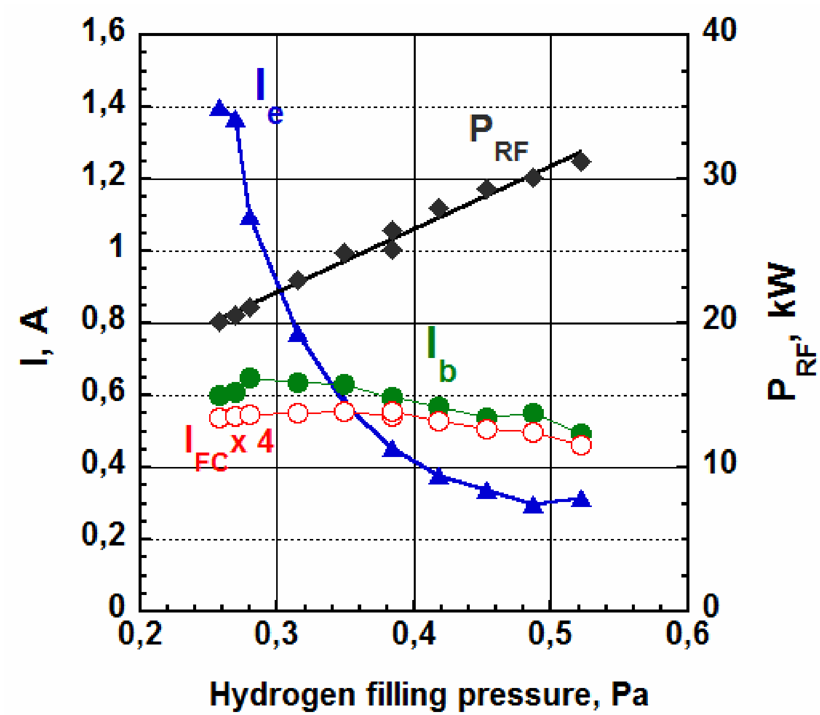
vs RF discharge power



Beam and electron currents are increased

The ratio of electrons to ions **0,5 ÷ 1**

vs Hydrogen filling pressure



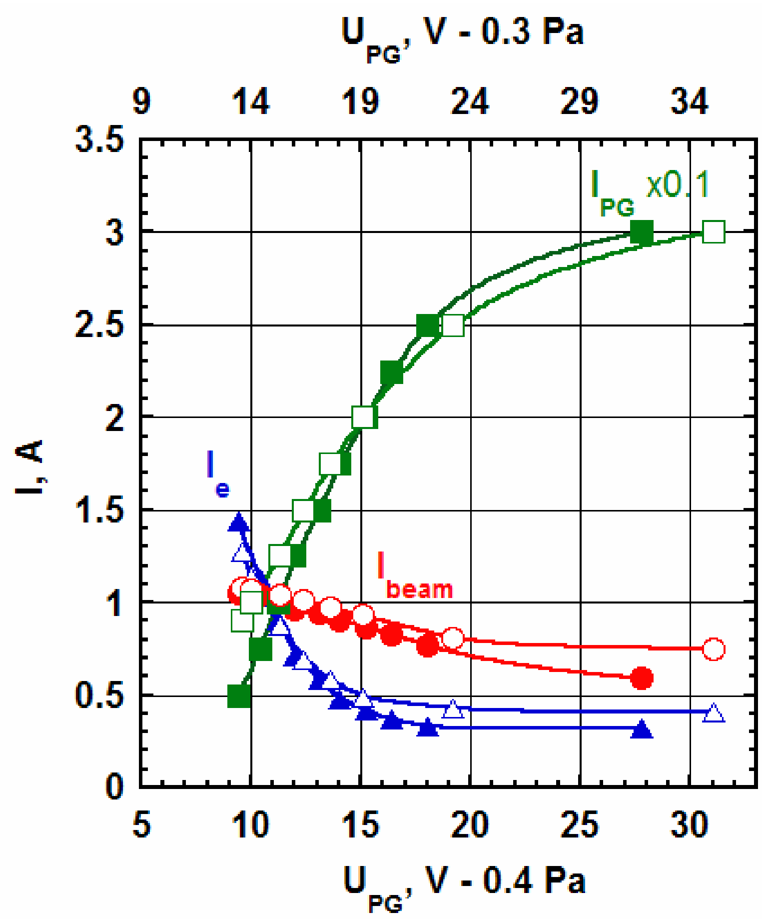
RF discharge power increases (at the fixed U_{RF})

H- ions stripping masks the H- production growth
(at pressures > 0.3 Pa)

Electron current decreases 5 times

Dependencies vs U_{PG}

For two Hydrogen pressure cases 0.3 and 0.4 Pa



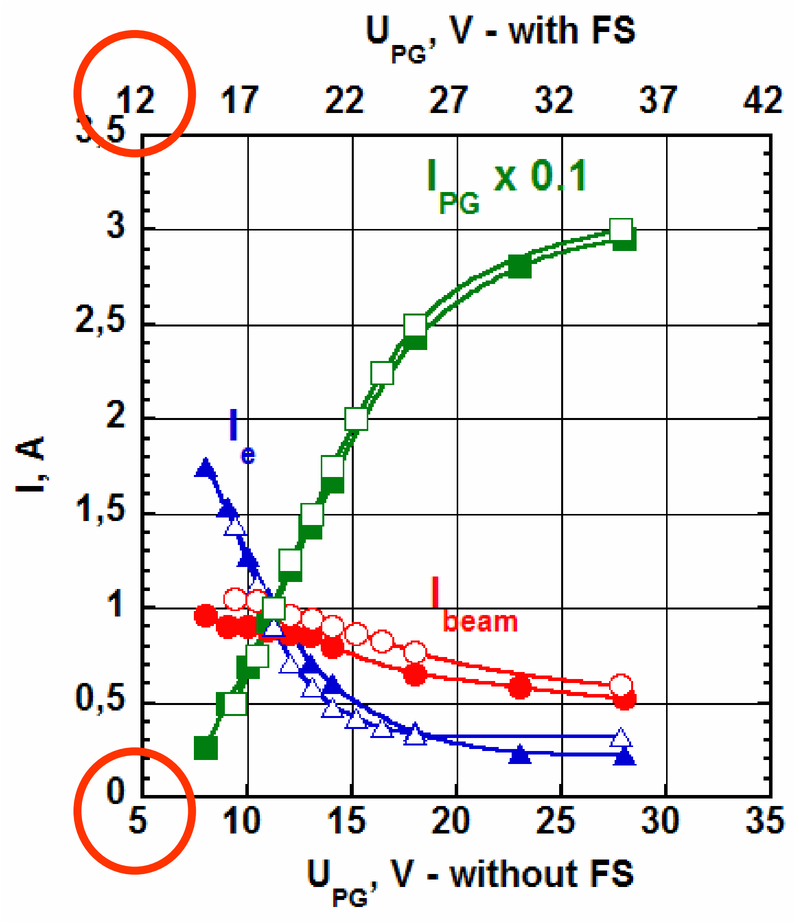
0.3 Pa– top axis X2, empty markers
0.4 Pa– bottom axis X1, solid markers

The values of emission currents depend on the potential difference, formed between the near-PG plasma and PG.

The coherent 4 V shift of dependencies along the PG potential axis displays the ~ 4 V higher plasma potential at lower hydrogen filling pressure 0.3 Pa

Dependencies vs U_{PG}

For two RF driver modifications - with and w/o FS



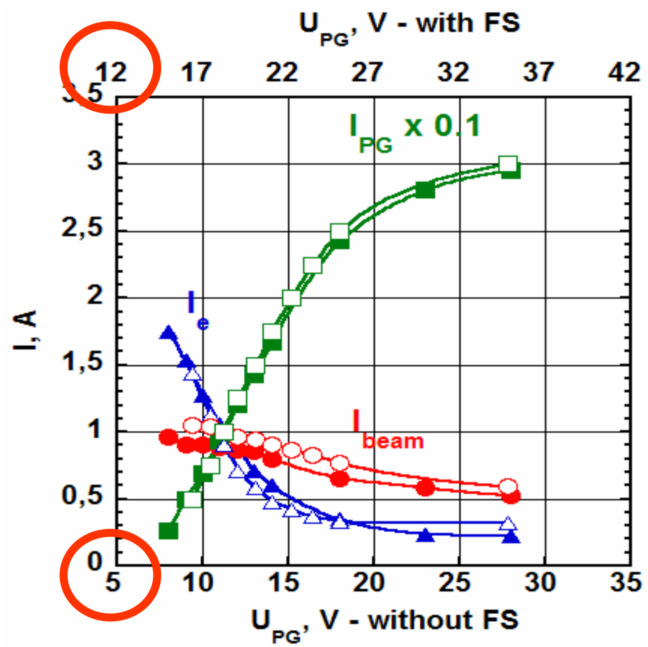
with FS – top axis X2, solid markers
w/o FS – bottom axis X1, empty markers

The coherent 7 V shift of dependencies displays the ~ 7 V higher plasma potential in the case of driver with FS

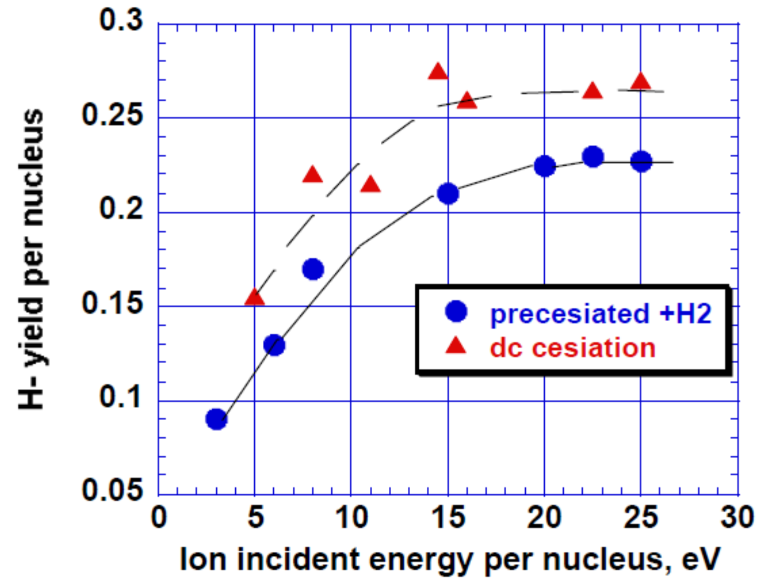
The similar maximal values of NI beam currents ~ 1 A were obtained for both driver cases

Independence from plasma potential

is important to clarify the H- production mechanism



M.Seidl et al. J.Appl.Phys., 79, 2896 (1996)



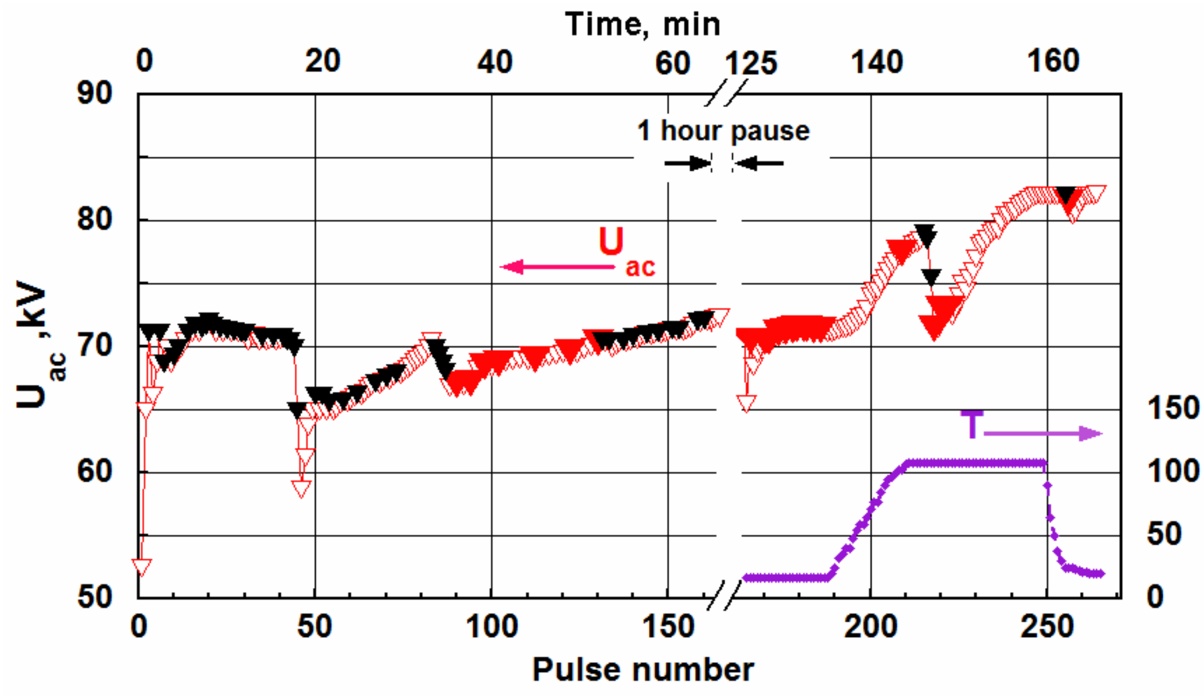
NI yield vs nucleus energy

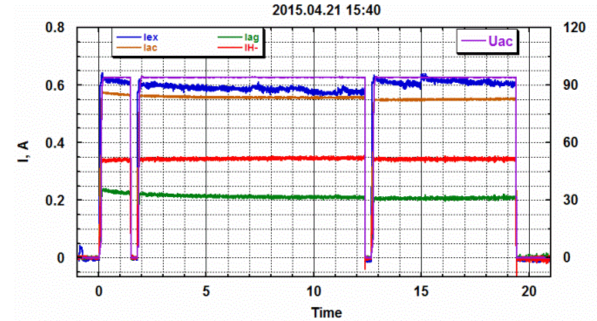
Positive ions, accelerated by ~ 7 V higher potential produces the same H- yield, if they have the energy > 20eV per nucleus

or

they lose their energy during transport from driver to PG (D Wunderlich et al, Plasma Sources Sci. Technol. 23, 015008 (2014). .

IOS Electrodes heating facilitates High Voltage Conditioning





△ Empty red triangles- no BD,

▼ solid black triangles –with BD

▼ Solid red triangles - with BD and HV recovery during pulse

T - temperature of thermal career.

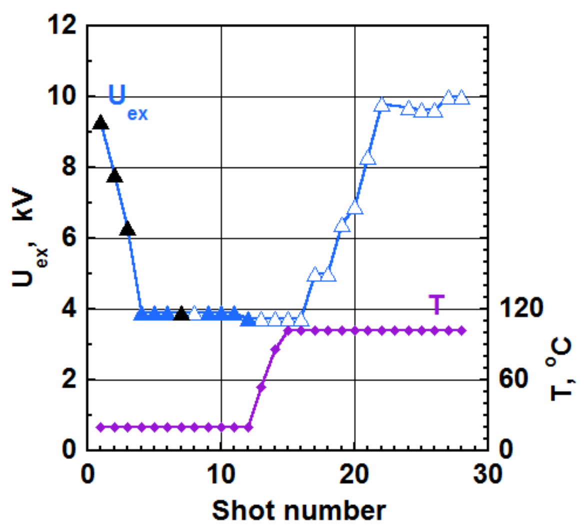
Acceleration gap Conditioning by HV pulses in vacuum.

Cold electrodes: U_{ac} = 72 kV after ~160 pulses, ~25% had BDs

15 min at 110 °C : U_{ac} = 82 kV after 50 pulses, ~16% had BDs

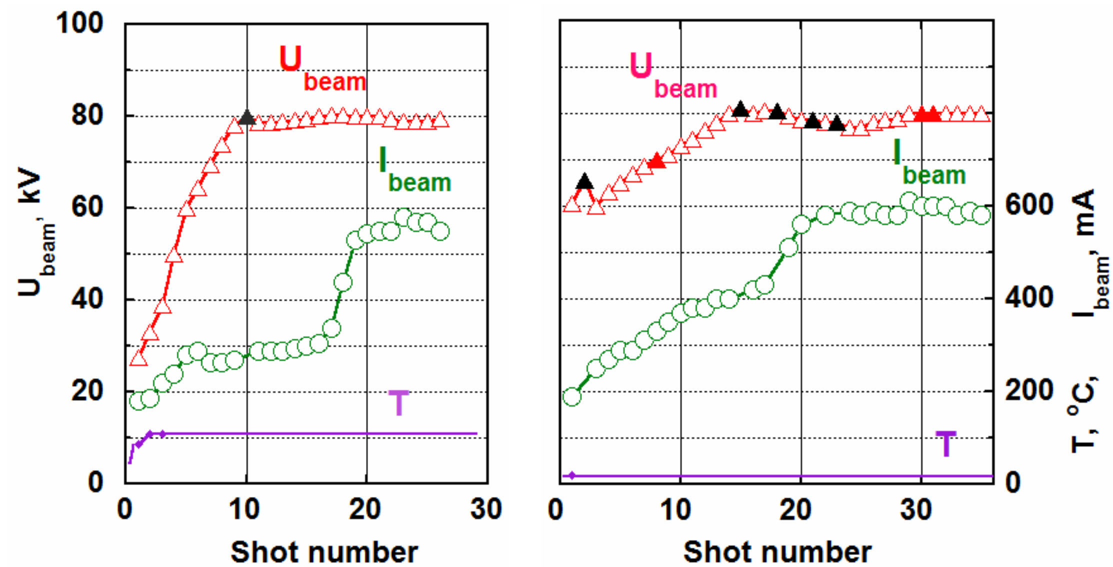
High Voltage Conditioning by beam

Extraction gap conditioning by beam



4 kV for cold electrodes
10 kV for 110 °C x 10 min

after 5-day stop **After 2 runs and night stop**



Starting conditioning by beam shots
At left (110 °C) - 80 kV after 19 pulses, 1 with BD
At right (20 °C)- 80 kV after 31 pulses, 8 with BD

Heating to 100 °C stipulates the cesium transport out of the IOS apertures to the periphery

Source Parameters and Status

	Project	Status (June 2015)
H- Beam current at 1.6 m, A	1.5	1.1
Beam Energy, kV	120	90
Pulse duration, s	100	2 (7)
H- emission current density, A/m^2	300	300
Number of Emission apertures	25	21
Hydrogen filling pressure, Pa	0.3	0.4

Thank You for attention !