Source Performance and Optimization in Cesiated Mode in ROBIN

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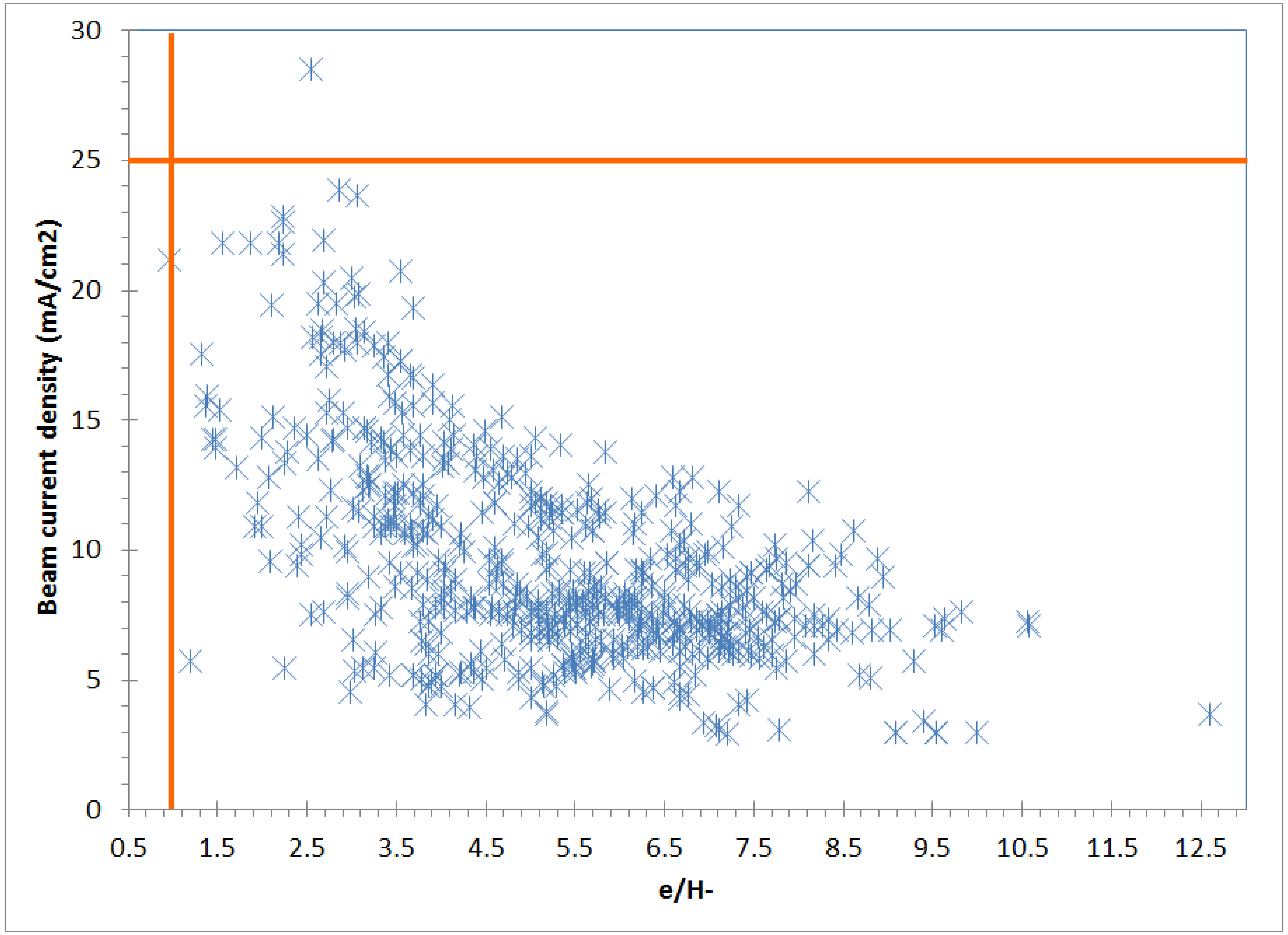
Outline

- Recap of the phase I Cesiated mode beam extraction experiments
- Lessons learnt
- Corrective measures
- Cesiated mode operation phase II
- Cesiated mode operation phase III

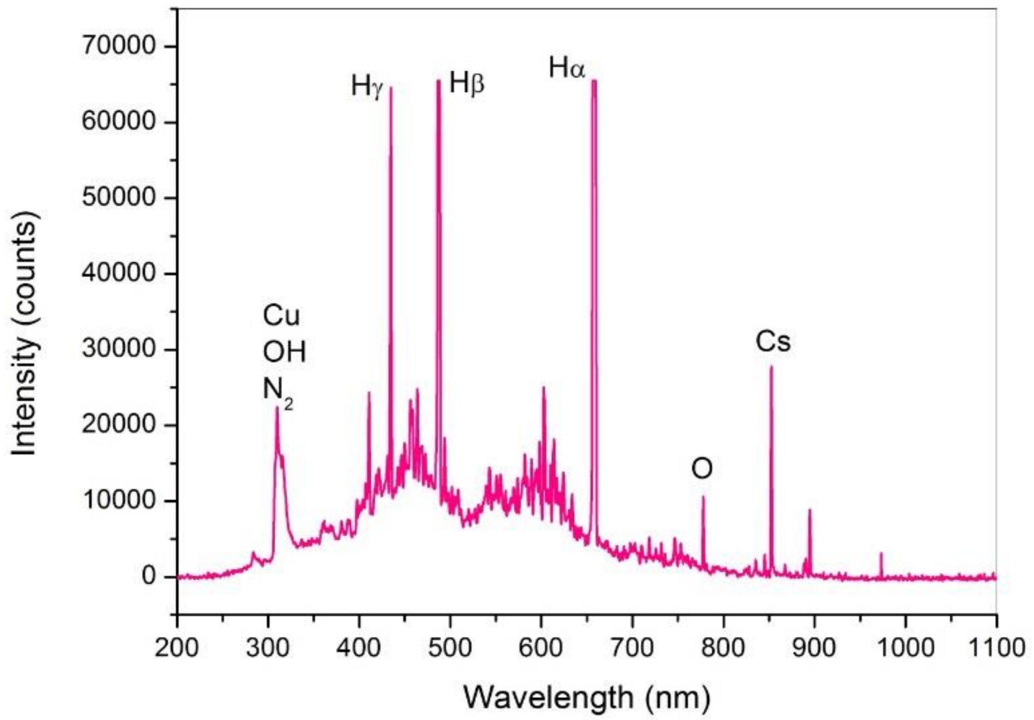
Source performance in Phase I of Cesiated mode beam extraction experiments on ROBIN test bed (2015-2017)



- Very high Cs consumption ~100 mg/hr
- Very high electron/ion ratio for most part of the campaign

Lessons learnt

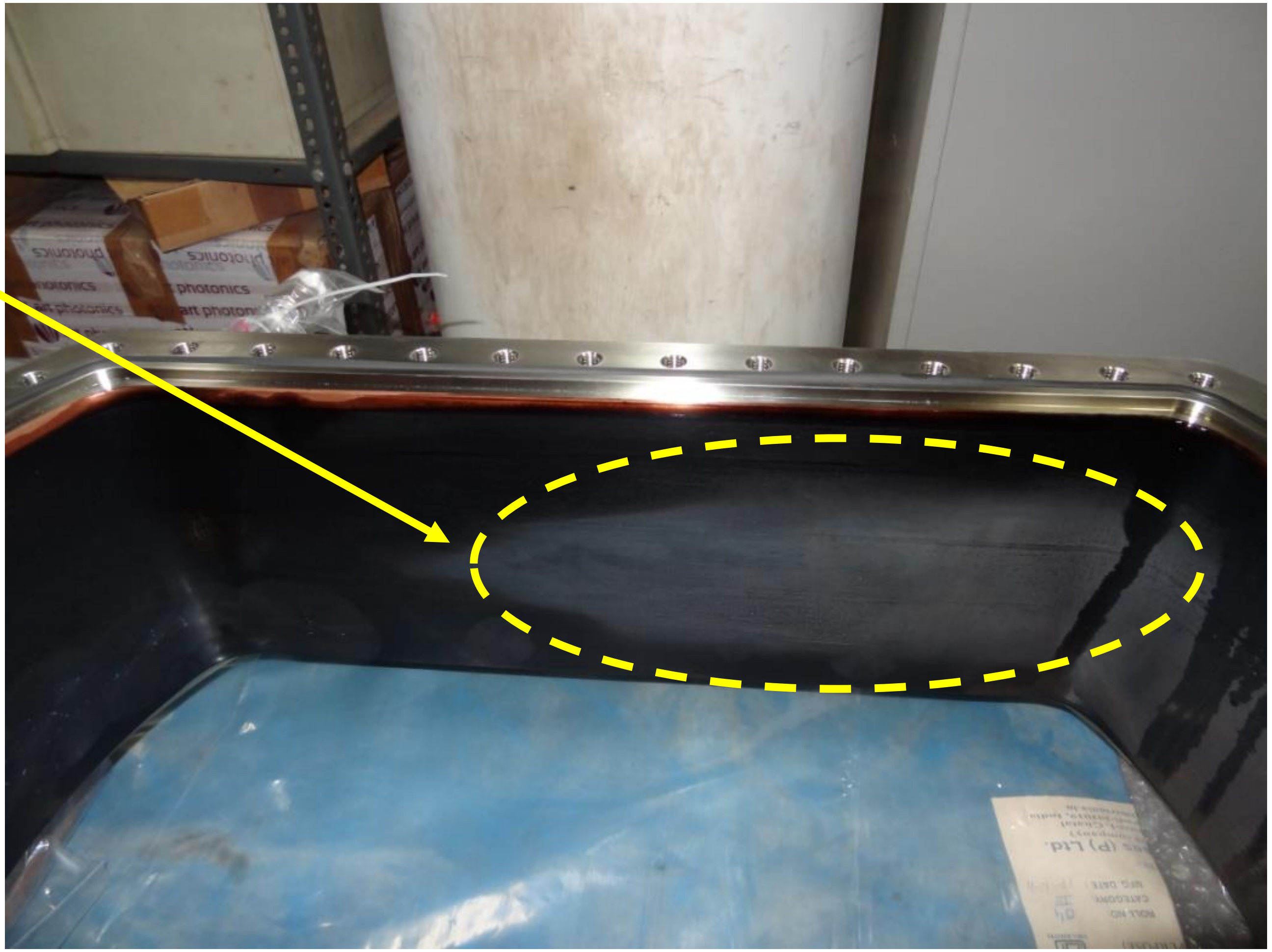
- High impurities in terms of residual gases (polyurethane gas tube, minor leaks)
- Frequent breakdowns and low RF power coupling due to over Cesiation.
- Could not establish the recipe to achieve optimum and stable source performance



- **Too much Cesium in the source**
- **Decision to clean**

ROBIN dis-assembly for cleaning

Wiping Plasma box walls with a wet cloth

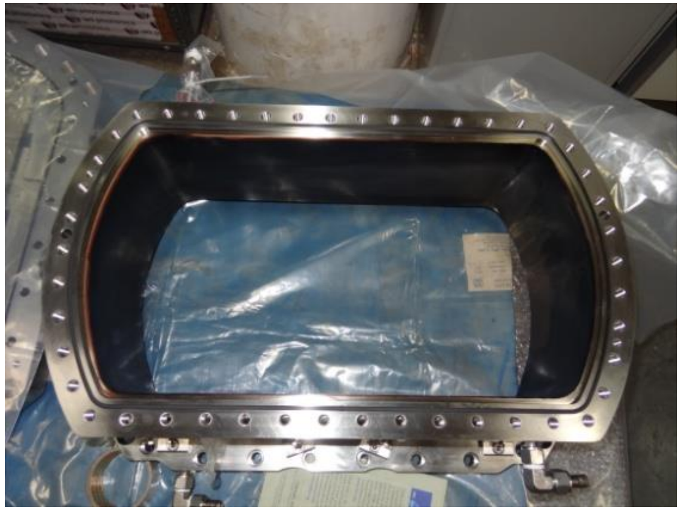
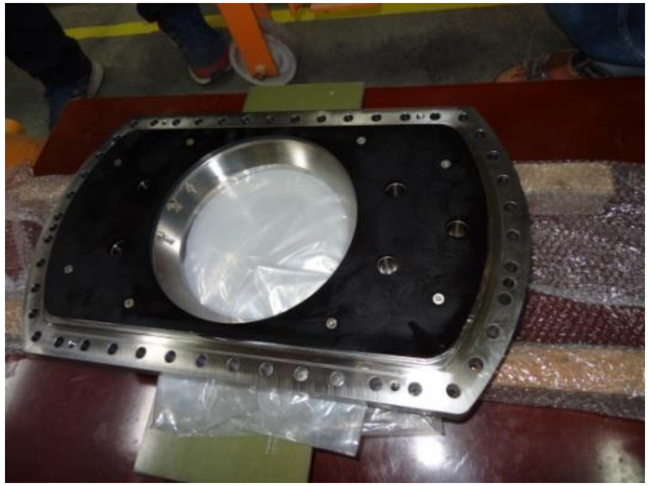
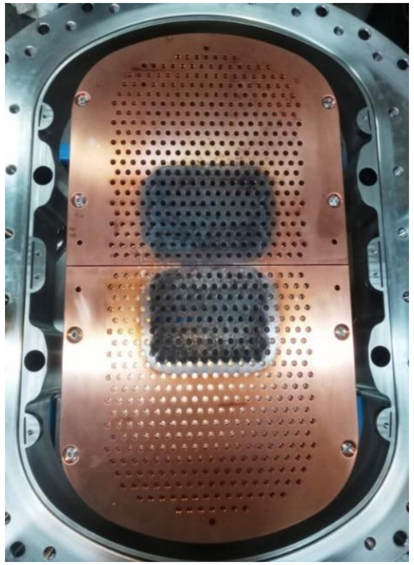


No shiny surface

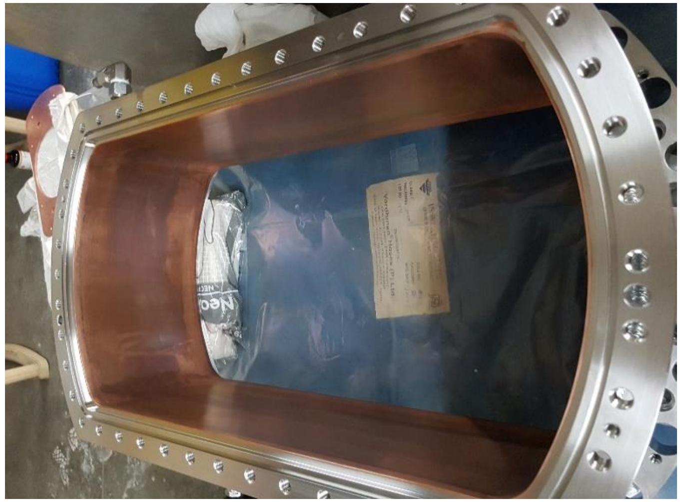
Good for operations…. To be established

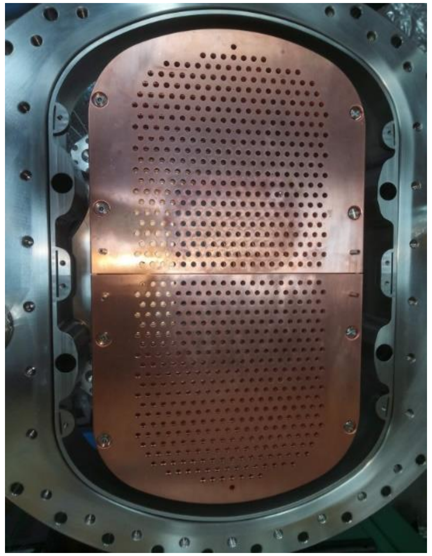
Cleaning with acid
25% phosphoric acid + soap solution + rising + drying (IPP)

Before :

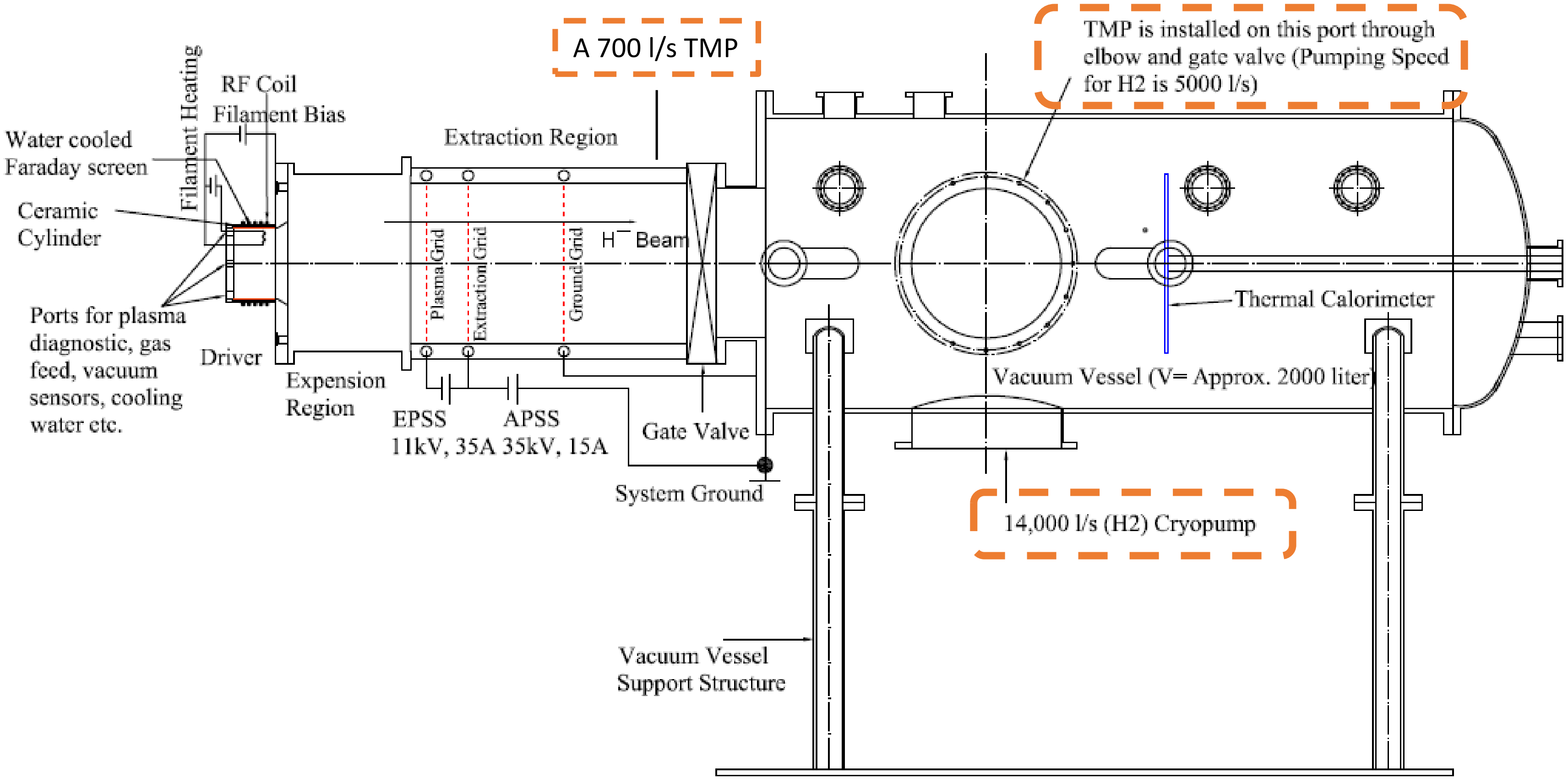
After :

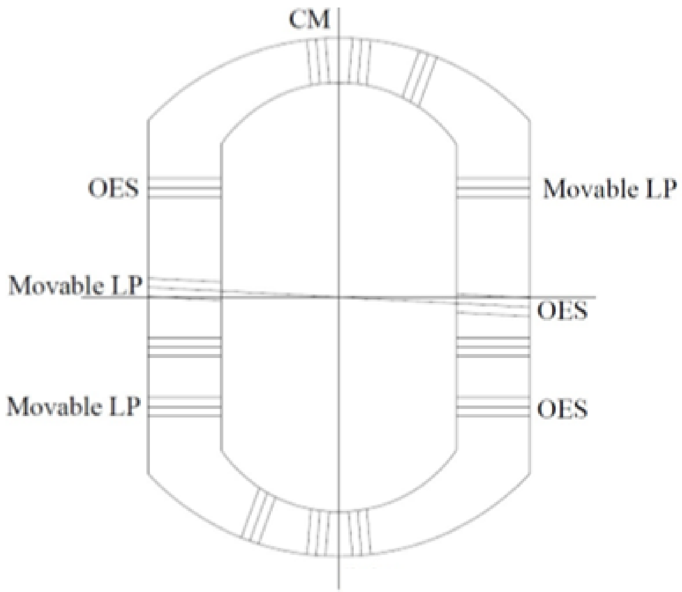




Reassembled ROBIN on the test stand

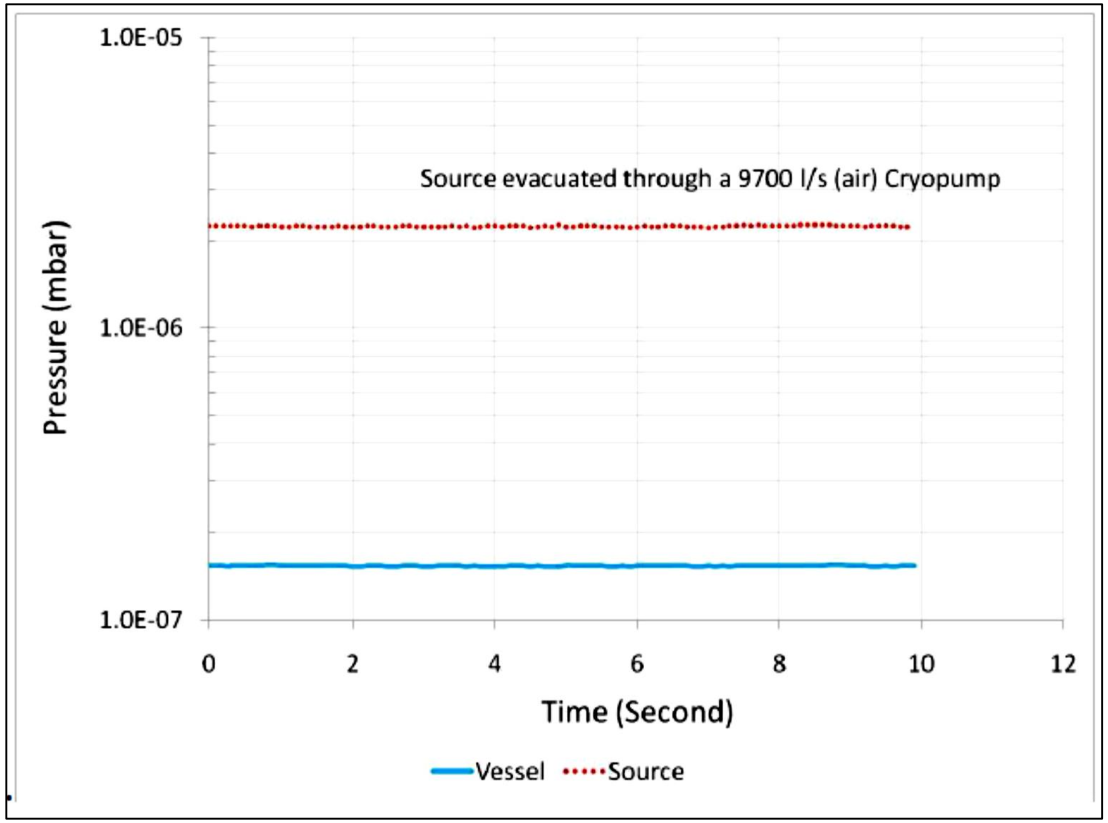
Pumping and diagnostics on ROBIN

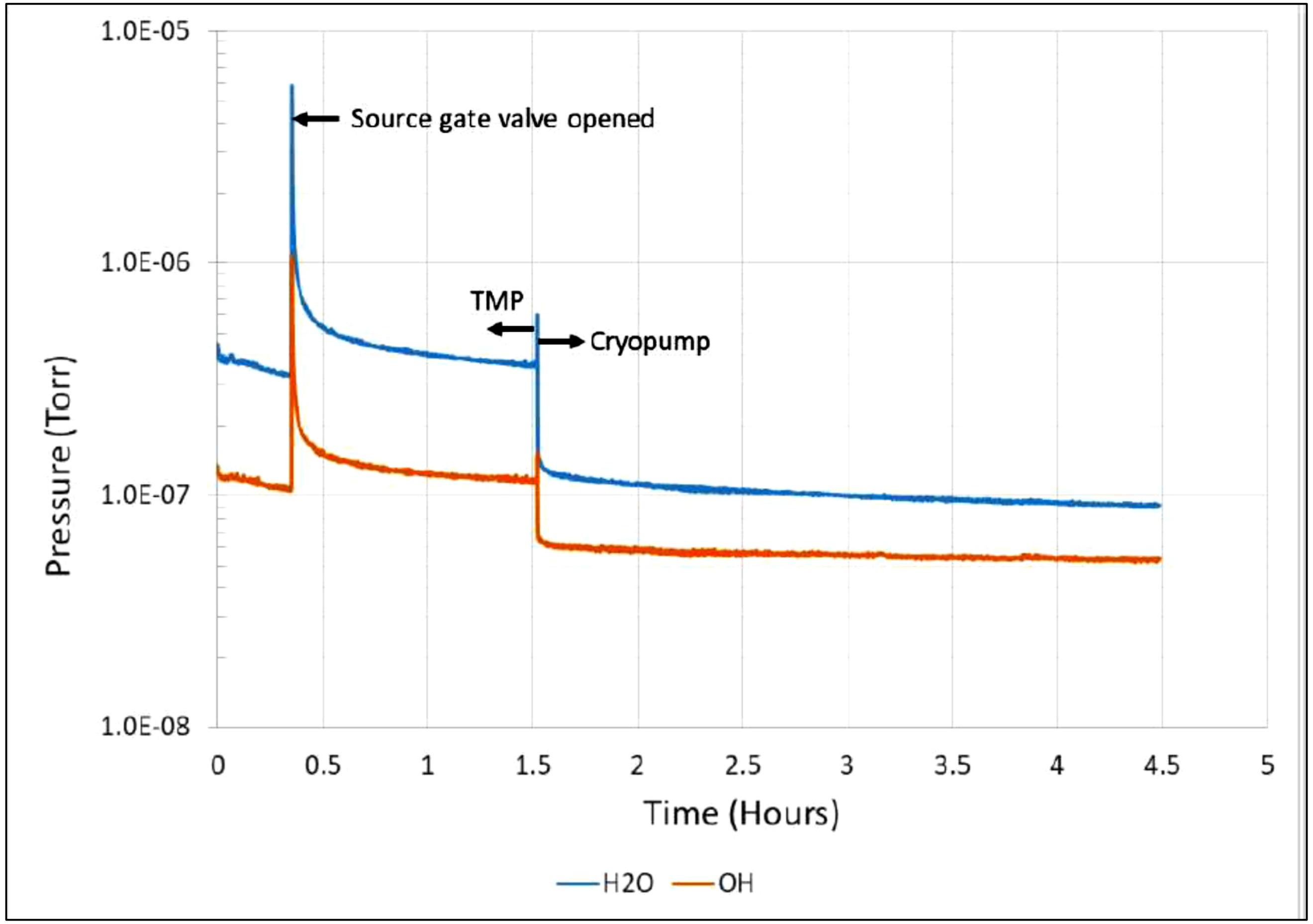




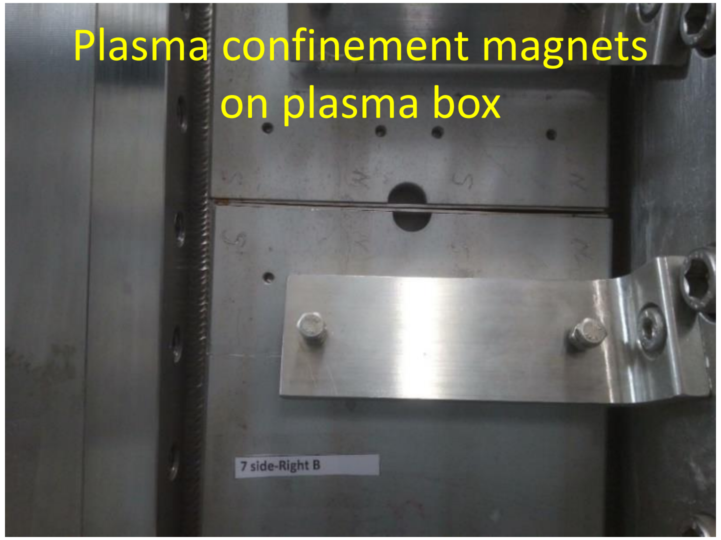
Diagnostics

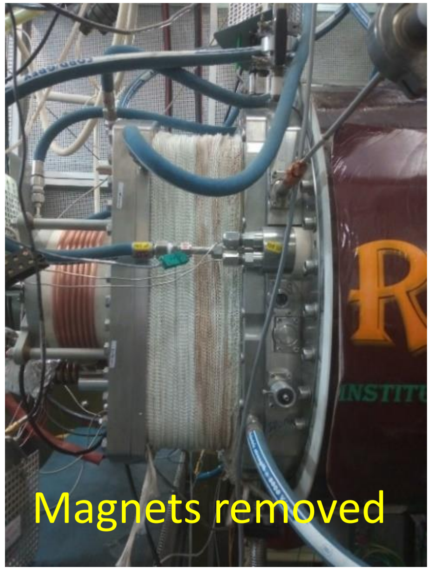
Pressure in the ROBIN source and the vacuum vessel (cryopumping)

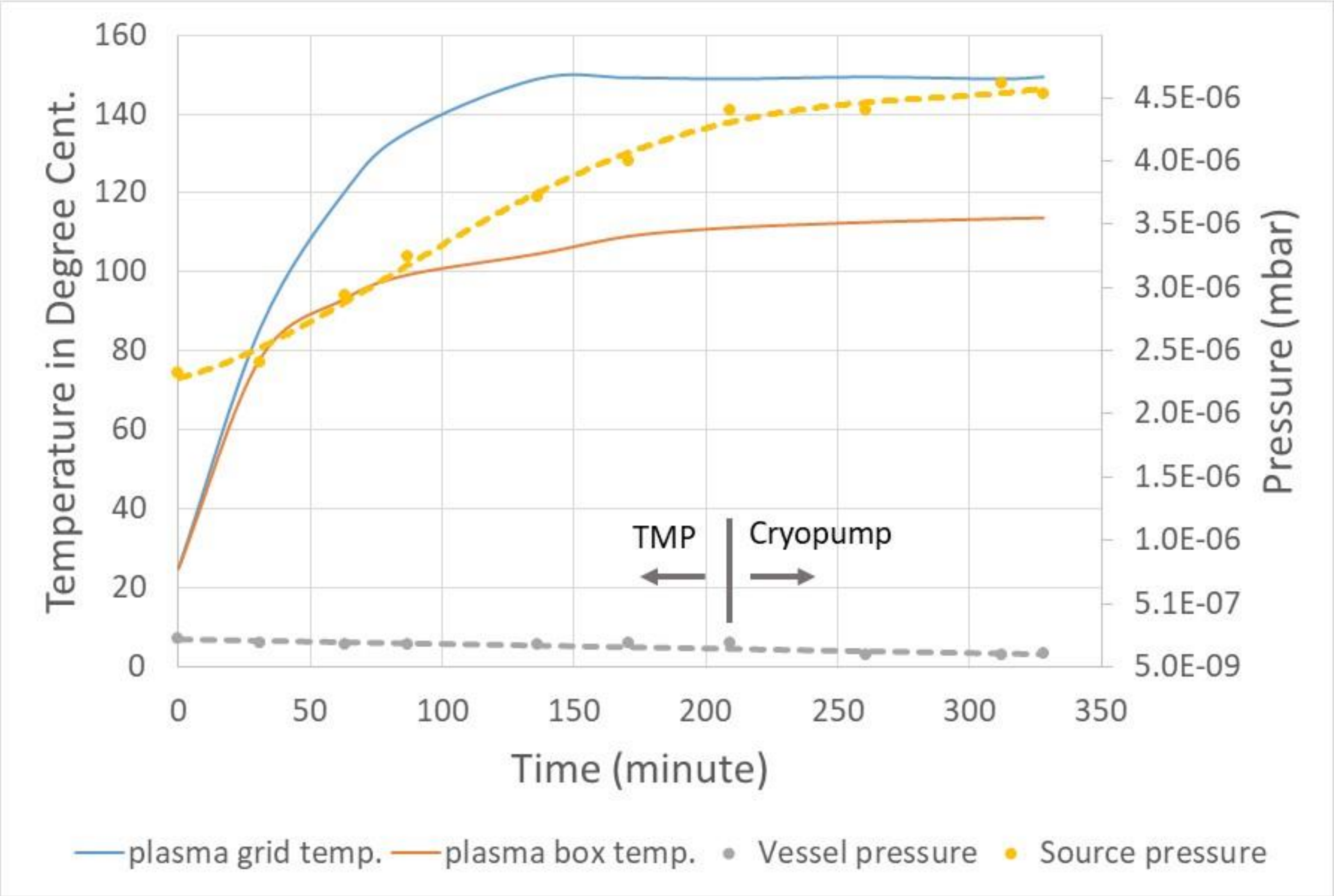




Baking operation prior to experiments

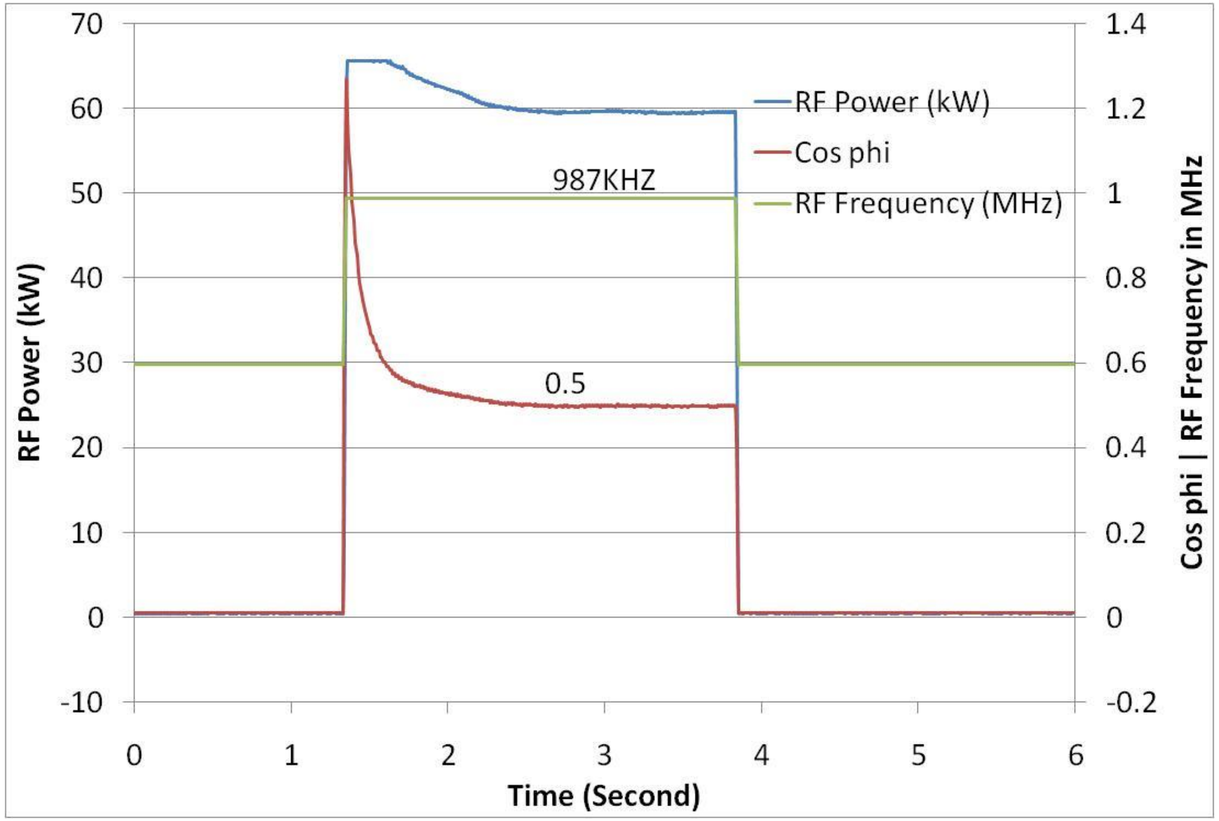




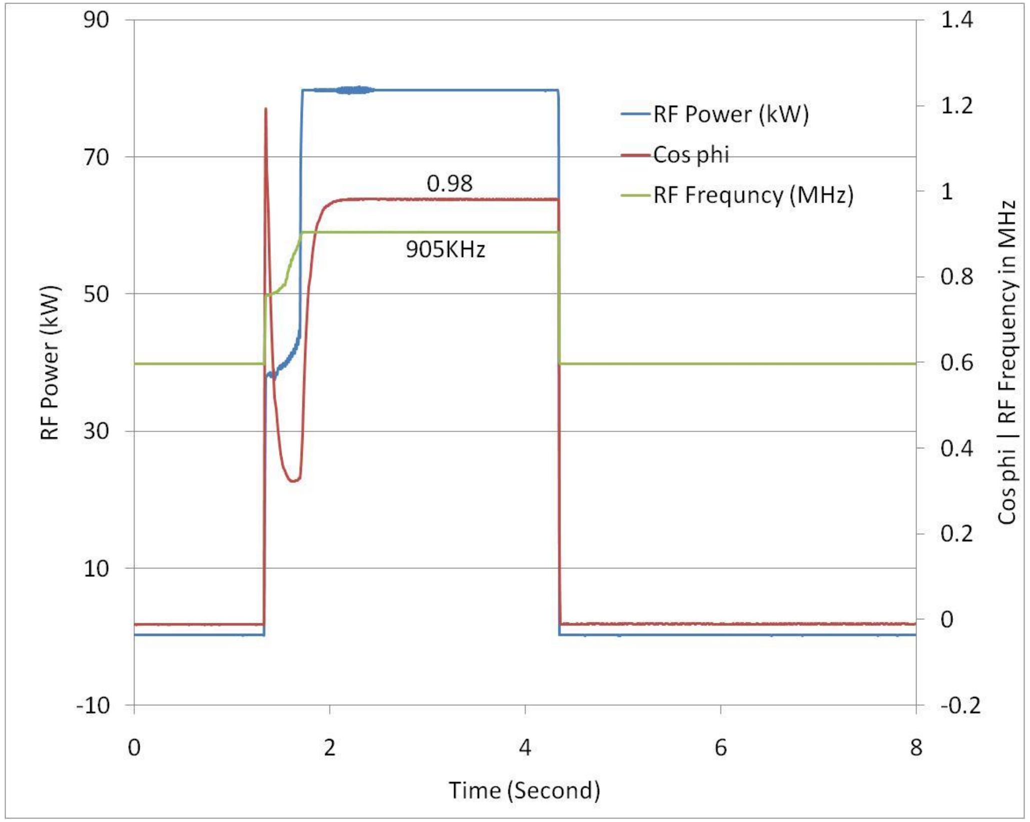


Improving RF power coupling through frequency tuning

60kW RF Power, Cos phi 0.5, Set Frequency **1MHz**

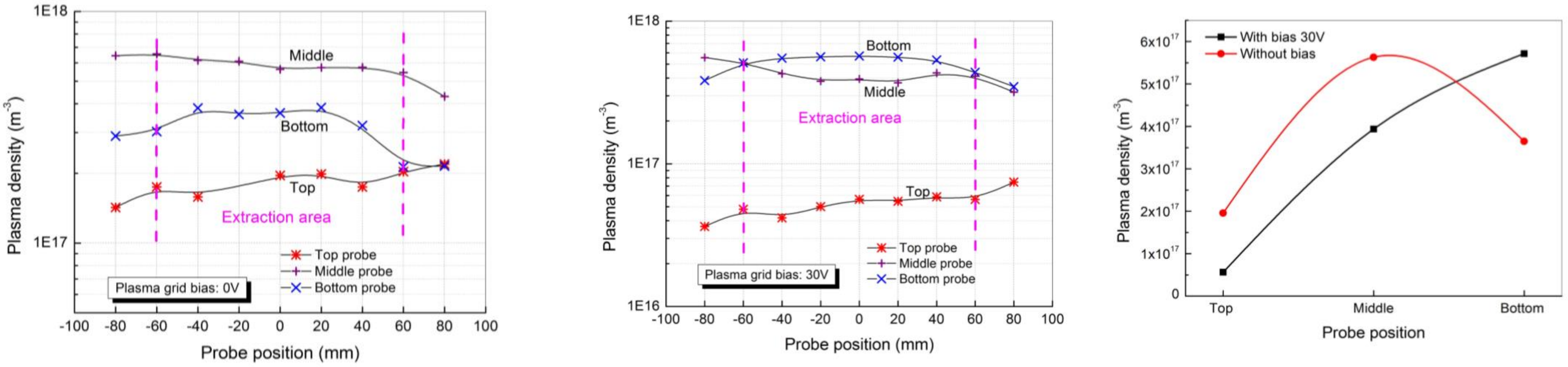


80kW RF Power, Cos phi 0.98, Set Frequency **937kHz**



Operations in volume mode (2020-21)

Plasma density as a function of probe position

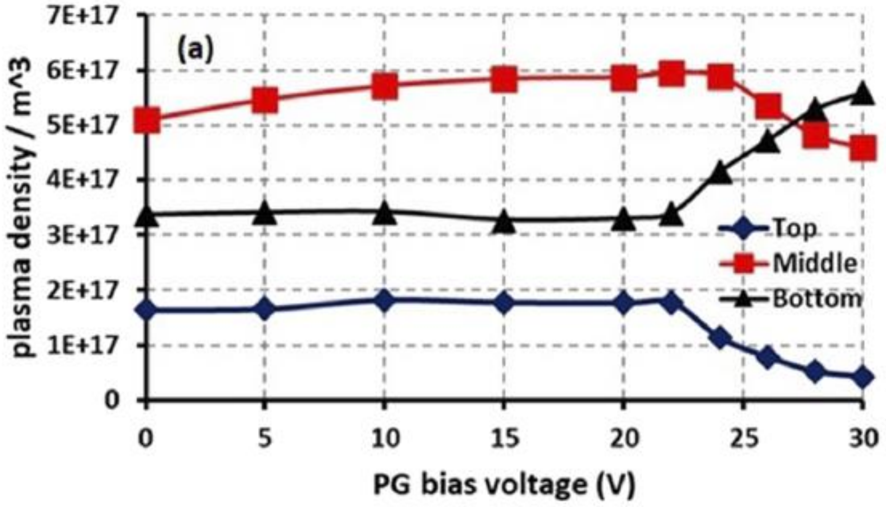


Without bias

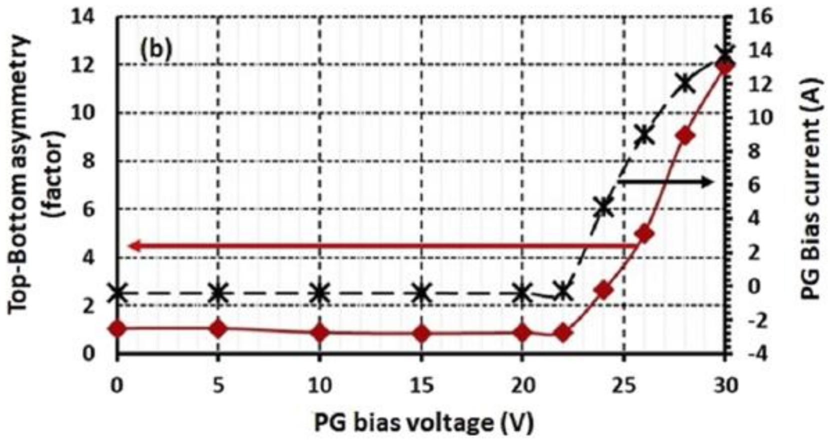
With PG bias : 30 V

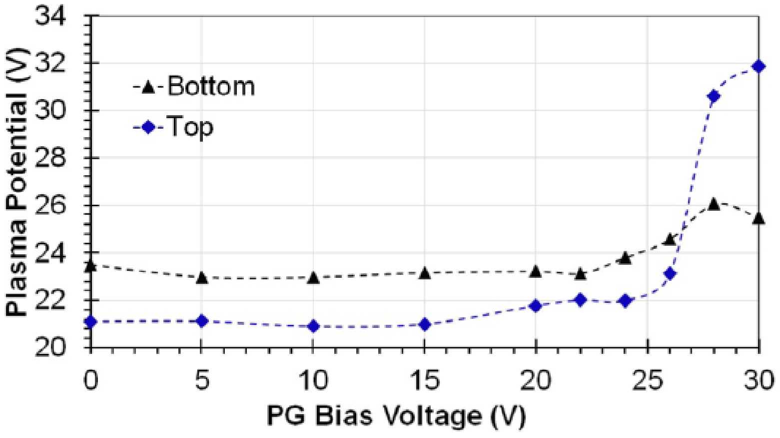
Operations in volume mode

Bias effect on plasma densities and potentials



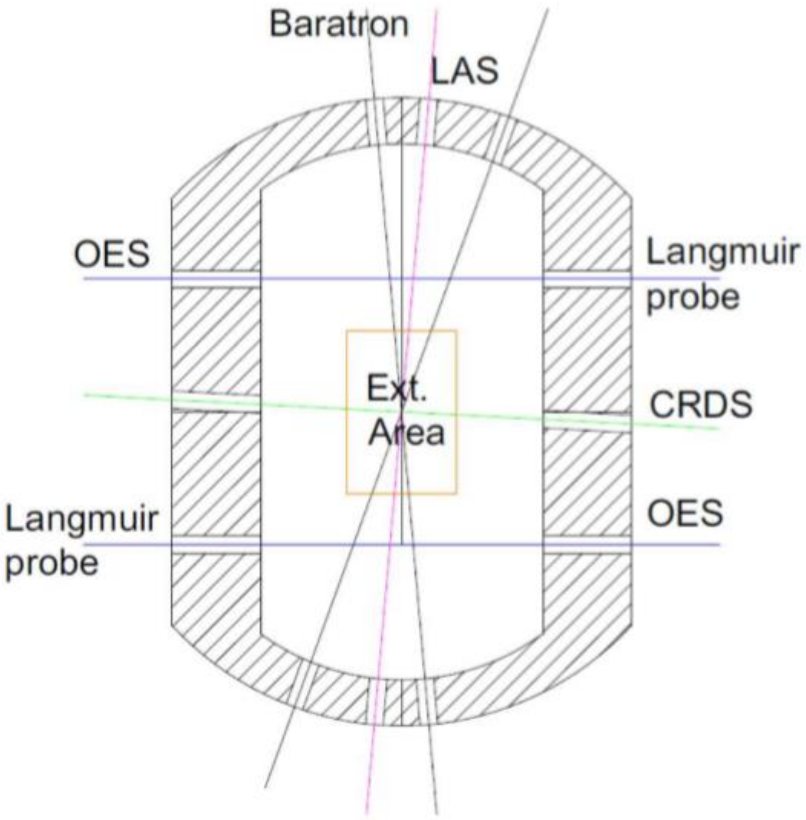
Bias scan : 0 - 30 V
50 kW RF power, 0.6 Pa pressure
probes located along the central vertical line of the source.





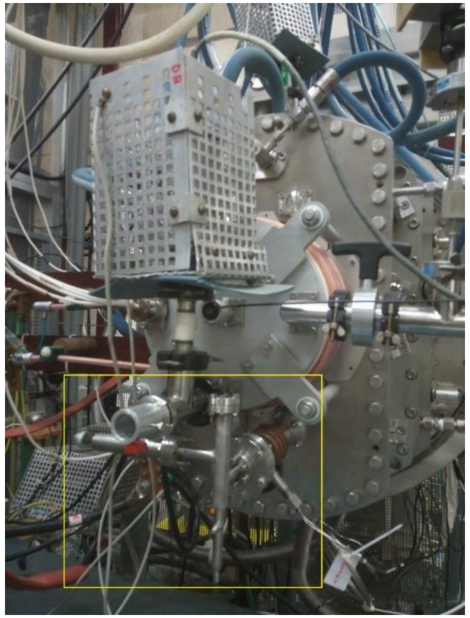
After 22V the sheath nature changes from electron repelling nature to electron attracting

Operations in Cesiated mode Phase II



Cesium Oven in ROBIN

Cs delivery tube



Cs oven position on source

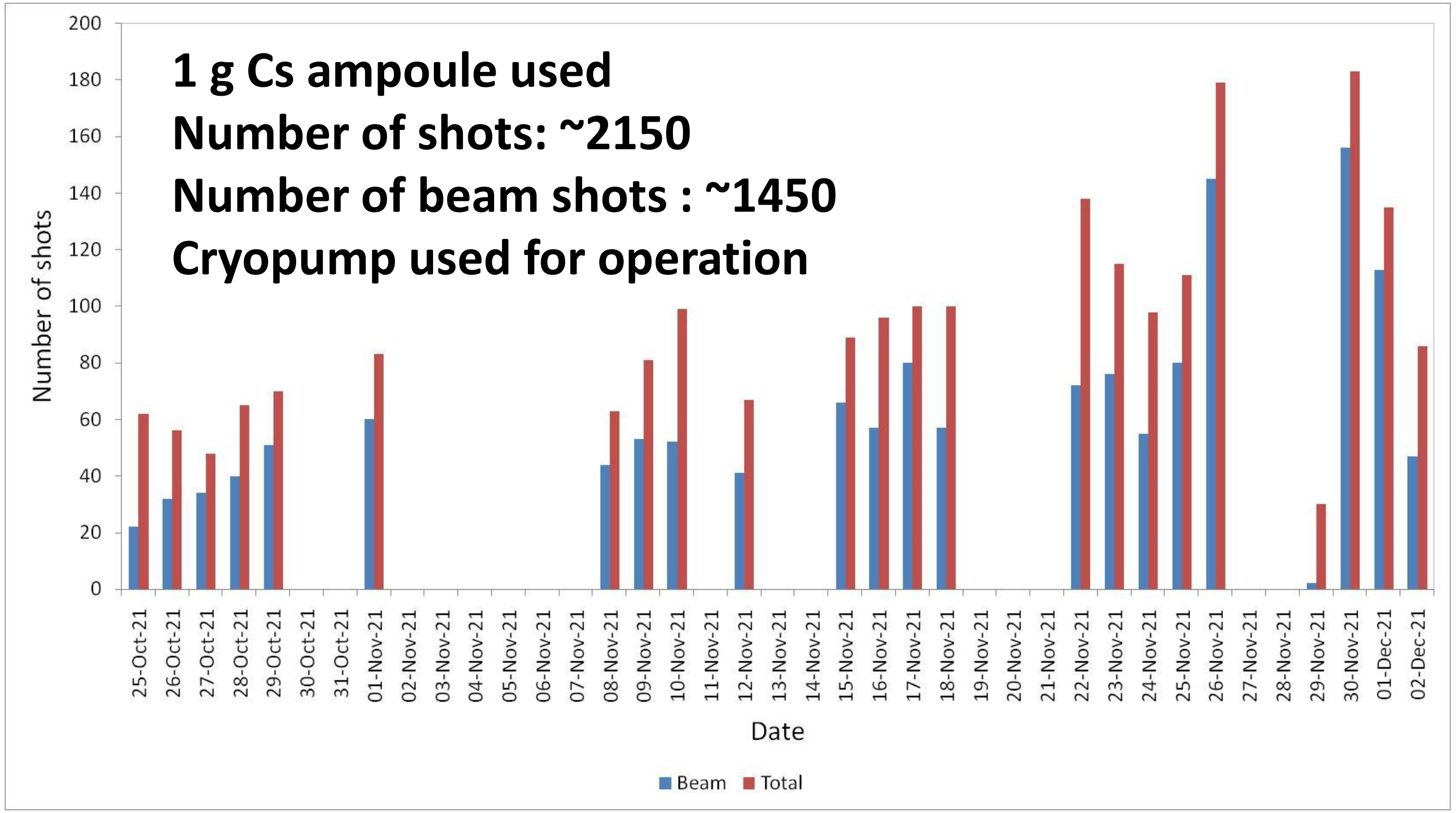
Diagnostic configuration change:
Probe and OES in the central port of the diagnostics flange replaced with CRDS set up

Cesium delivered to the source through 8mm OD and 6mm ID tube cut at 45° with respect to tube axis and **positioned below driver on source back plate**.

Objectives of the campaign

25/10/21 to 02/12/21

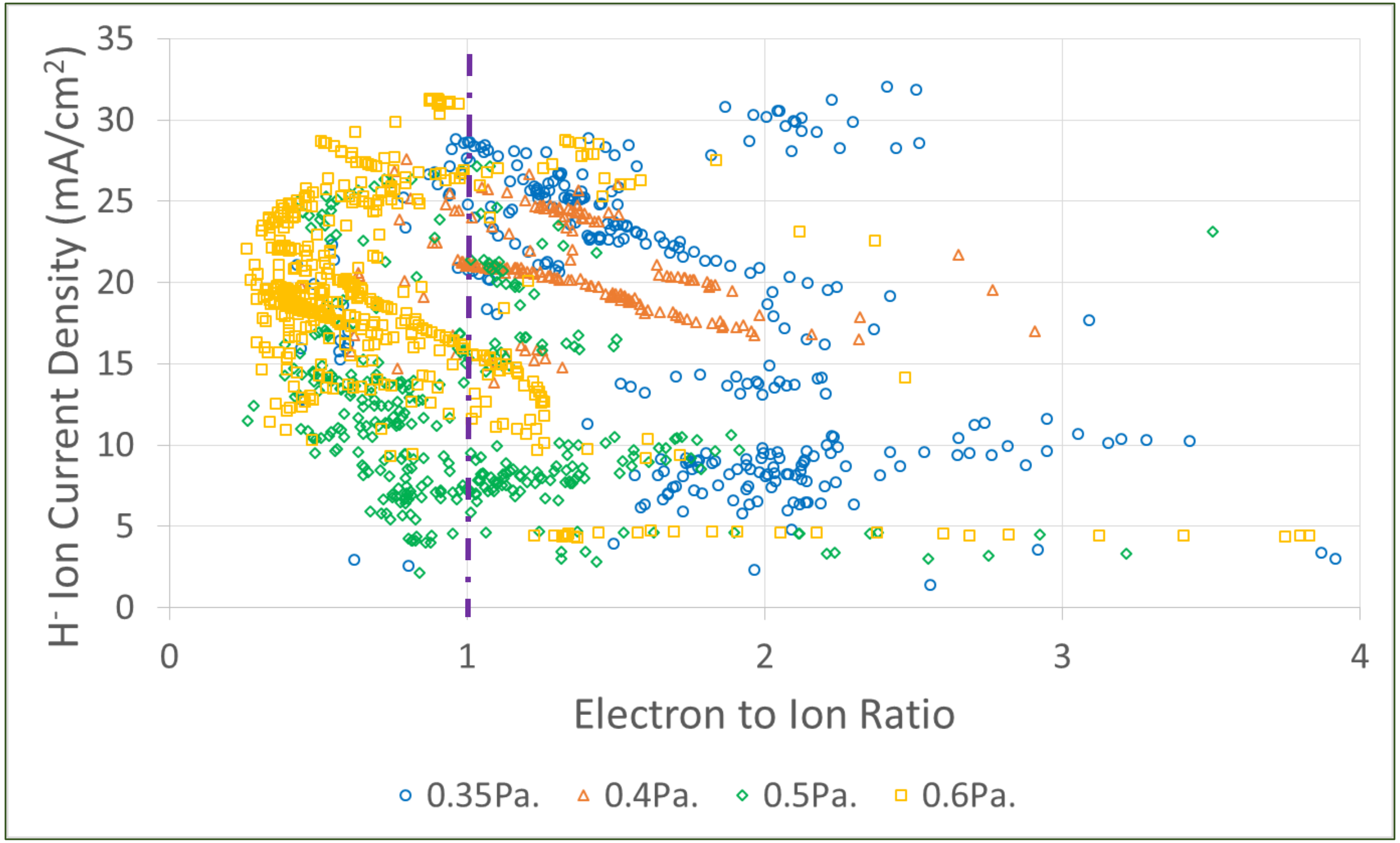
- Optimize the source performance in terms of *H⁻ ion current density* and *electron to ion ratio* with minimal Cesium (Cs) consumption.
- Characterize the ion source for various source operating parameters.
- Cs Conditioning to get the optimum source performance with minimal Cs consumption.



Source operational parameters

Particular	Value
RF Power	30-80 kW
Source Filling Pressure	0.35, 0.4, 0.5, 0.6 Pascal
Extraction Voltage	2-8 kV
Acceleration Voltage	6-24 kV
Grid Bias Voltage	0-32V
Source Components Temperature	40˚C
Plasma Grid Temperature	150˚C
Cesium Oven Reservoir Temperature	100-210˚C (ΔT 20-50˚C)
Beam on time	0.5 – 2 Second

Source performance over the full campaign phase II



j_{H-}>30 mA/cm^2 and e/ion ratio < 1 achieved for higher filling pressure 0.6 Pa

j_{H-}>25 mA/cm^2 and e/ion ratio < 1 achieved for filling pressure 0.5 Pa

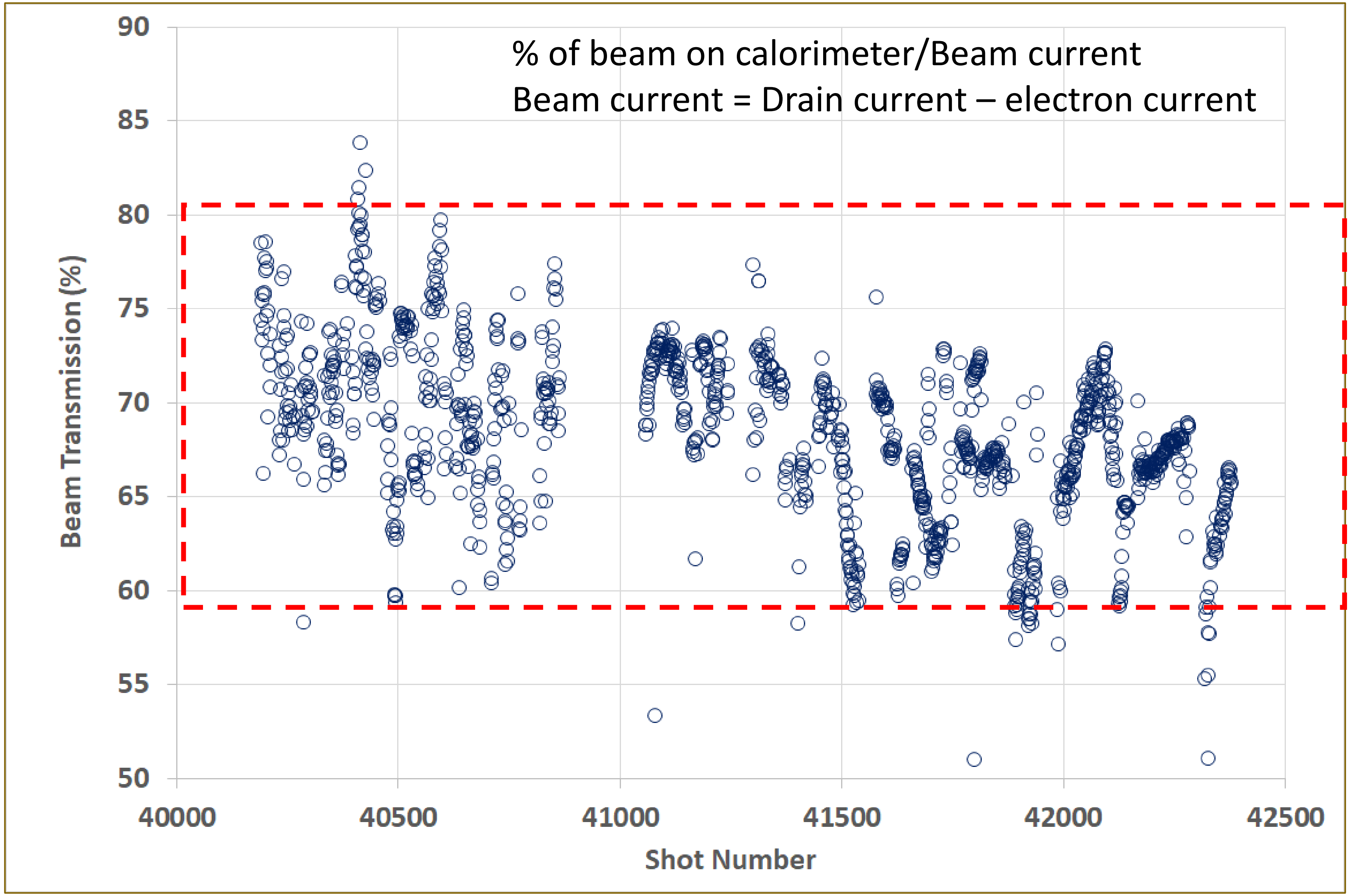
j_{H-}>25 mA/cm^2 and e/ion ratio <1 1 for filling pressure 0.35 Pa; j_{H-}>30 mA/cm^2 and e/ion ratio > 2

End of campaign Cs exhausted

Cs consumption : 12 mg/hr ; factor of 8 reduction than phase I

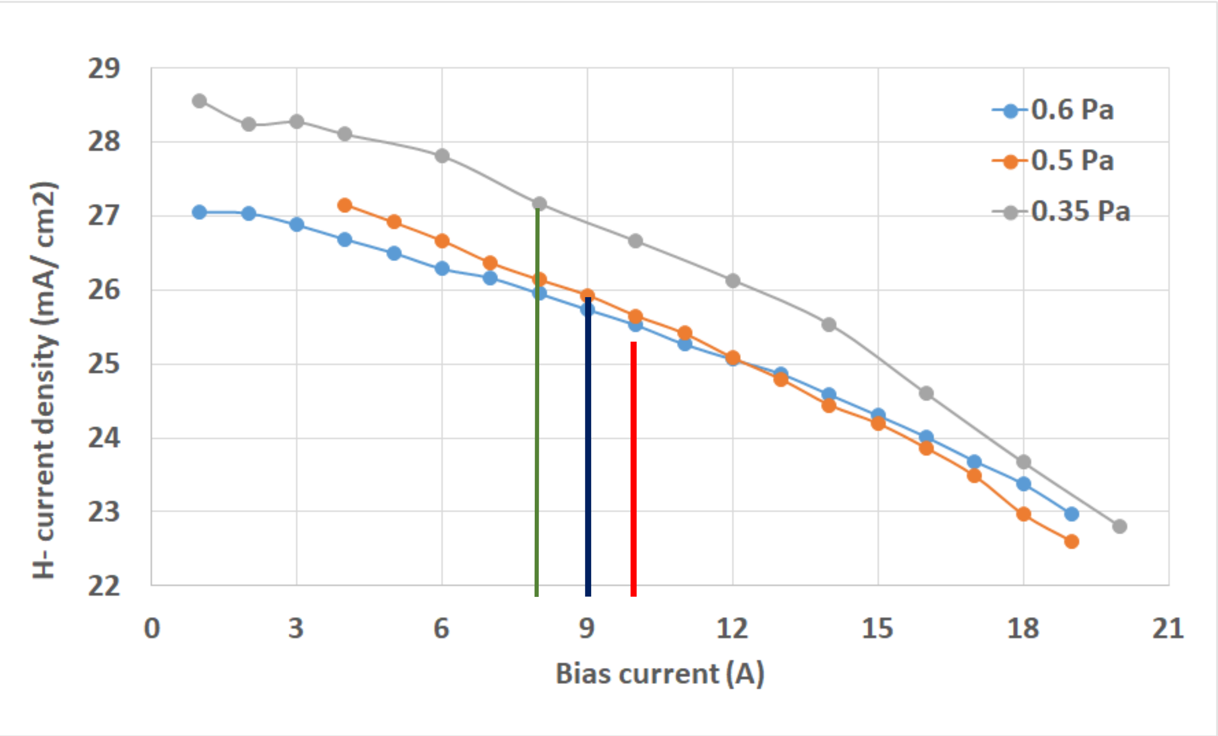
Lower pressure operation ; ITER relevant Phase III operation

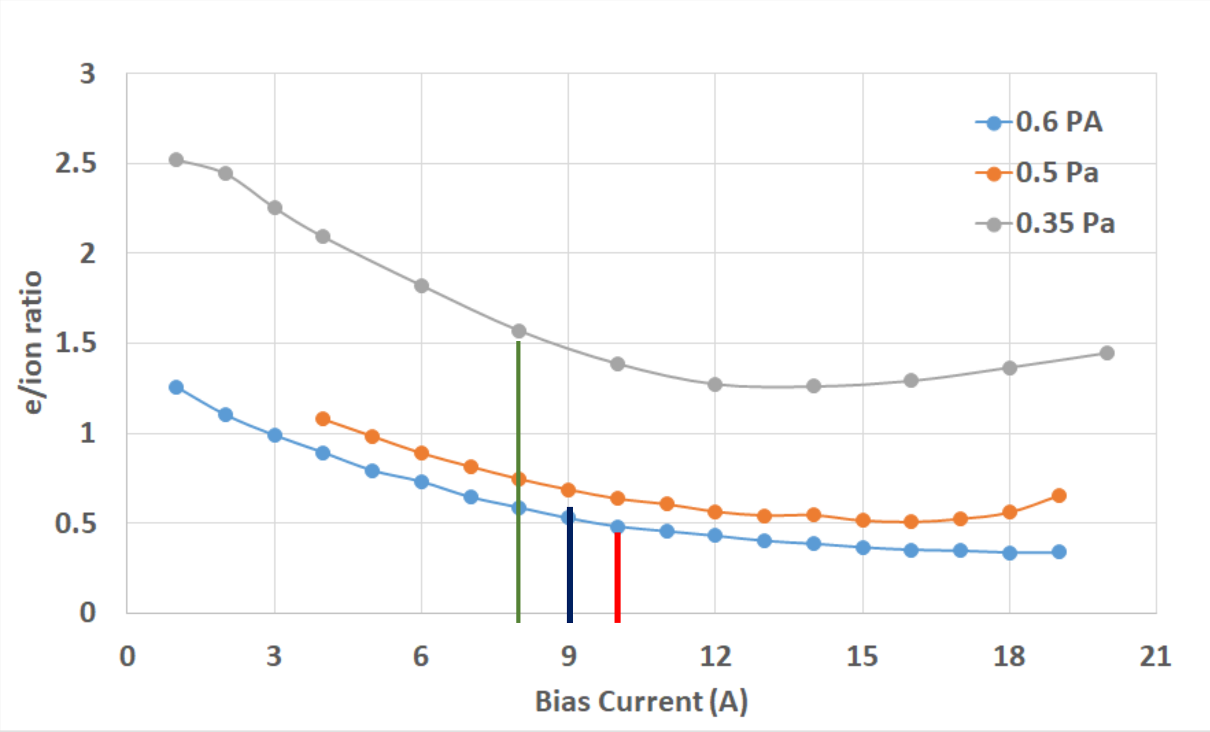
Transmitted beam



Bias scan and pressure dependence

RF power 75kW, Extraction Vol. 7kV, Acceleration Vol. 21kV

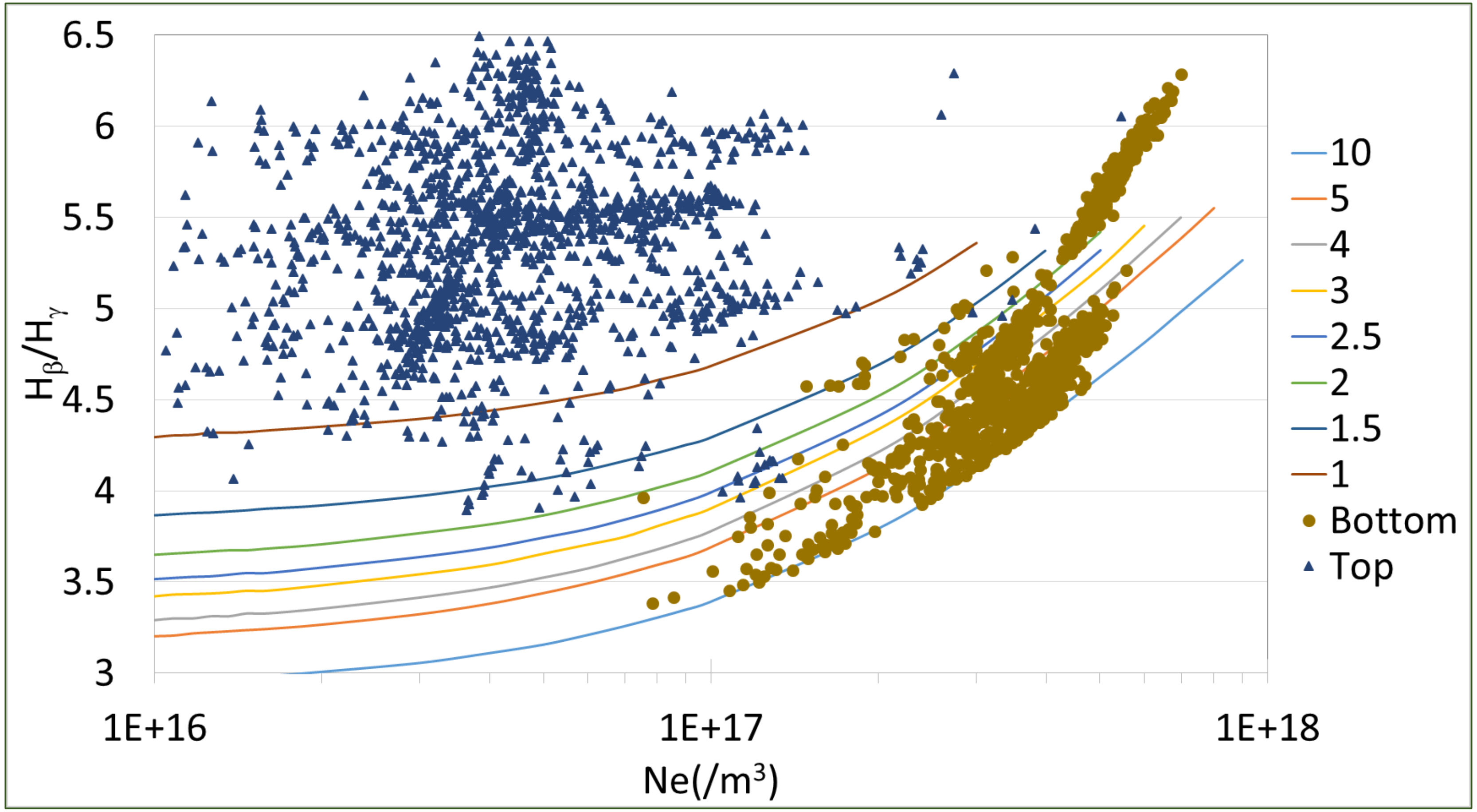




Optimal bias is pressure dependent : <u>Bias scan for each filling pressure is required</u>

Temperature asymmetry

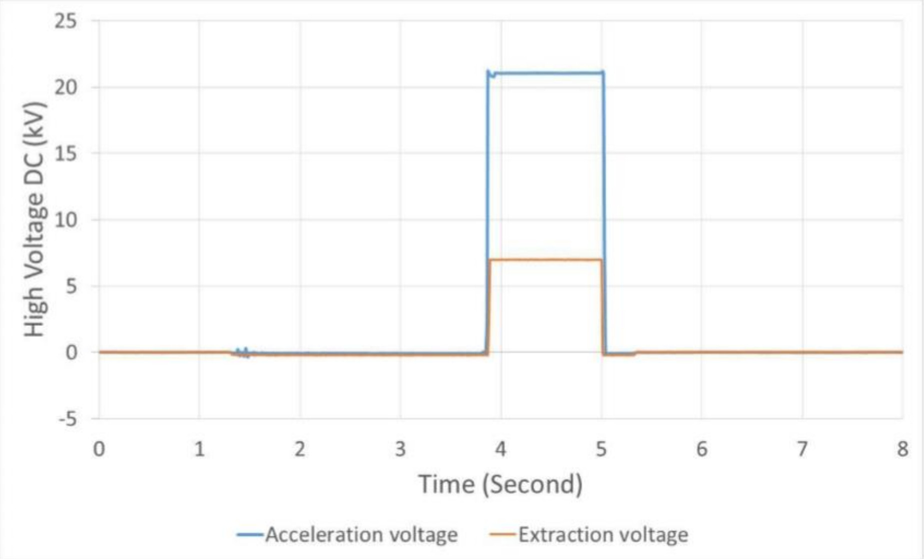
H_β / H_γ from CR model as a function of density for different electron temperatures

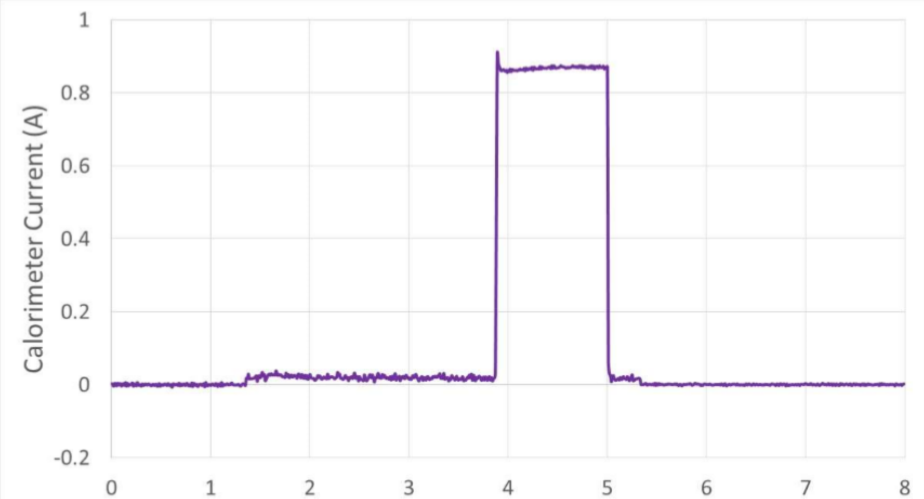


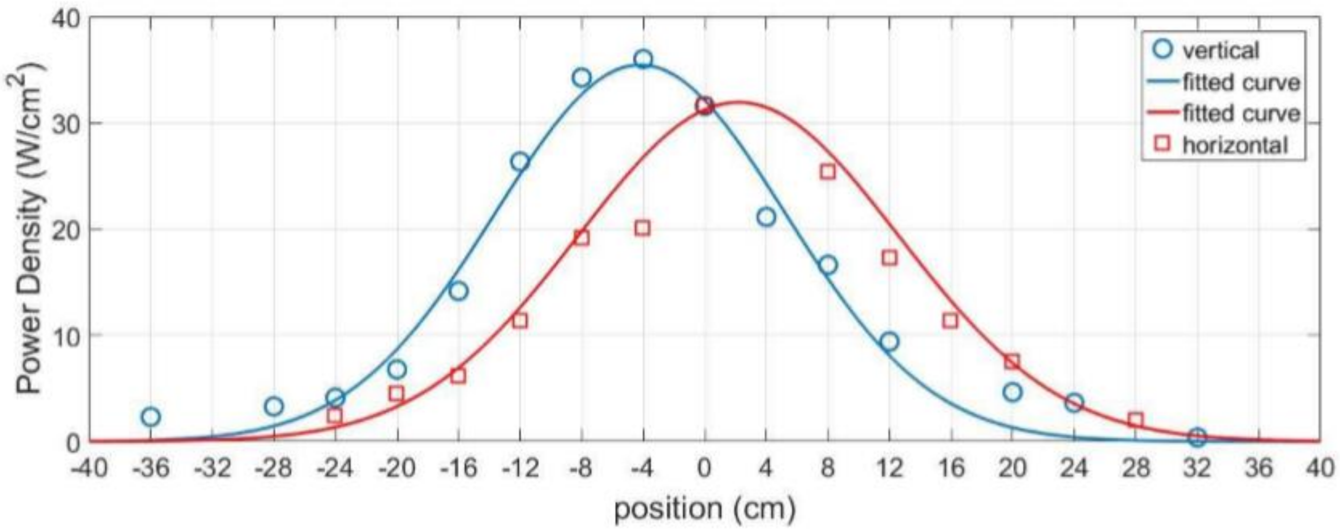
Plot reference

Thesis: Data analysis of an optical emission spectroscopy diagnostic in NIO1 experiment; Luca Vialetto

Estimated power deposition on calorimeter in ROBIN





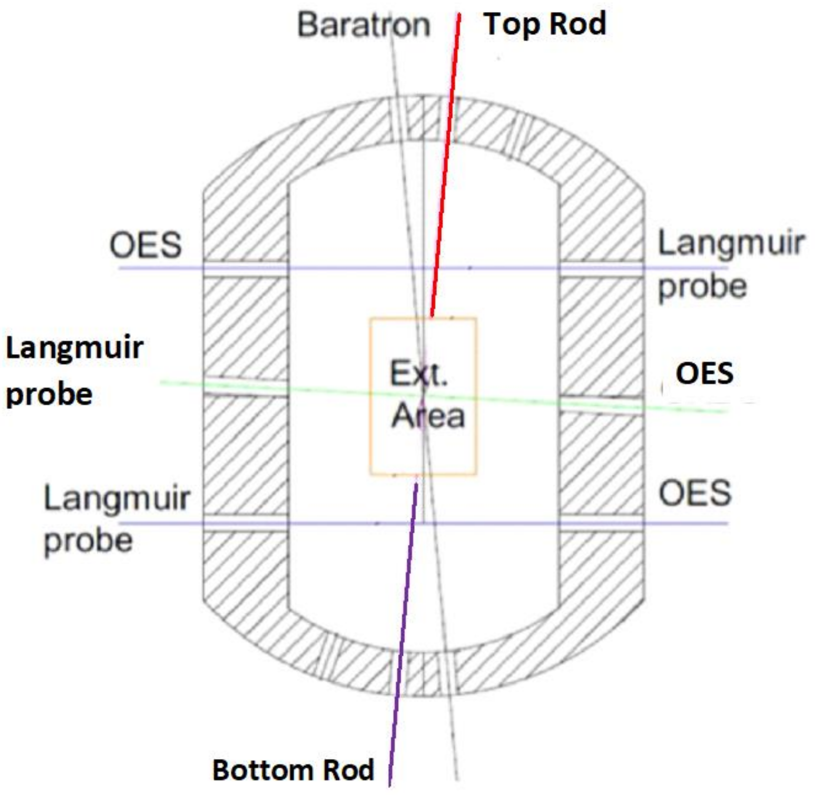


$$P = V \cdot I \ = 20.75kW$$

$$P_{total} \ = \left(\frac{mC_p \Delta T \ \sigma_V \sigma_H}{A \cdot t} \right) \cdot \pi \ = 22.45kW$$

Phase III of operation

Particular	Value
RF Power	60-78 kW
Source Filling Pressure	**0.3,0.35, 0.4 Pa**
Extraction Voltage	2-**11** kV
Acceleration Voltage	6-**35** kV
Grid Bias Voltage Additional electrodes used at top and bottom locations	0-32V 0-32V for each electrode
Source Components Temperature	40˚C
Plasma Grid Temperature	~ 170-180 ºC
Cesium Oven Reservoir Temperature	100-190˚C (ΔT 30-50˚C) lower than phase II
Beam on time	0.5 – 1 Second

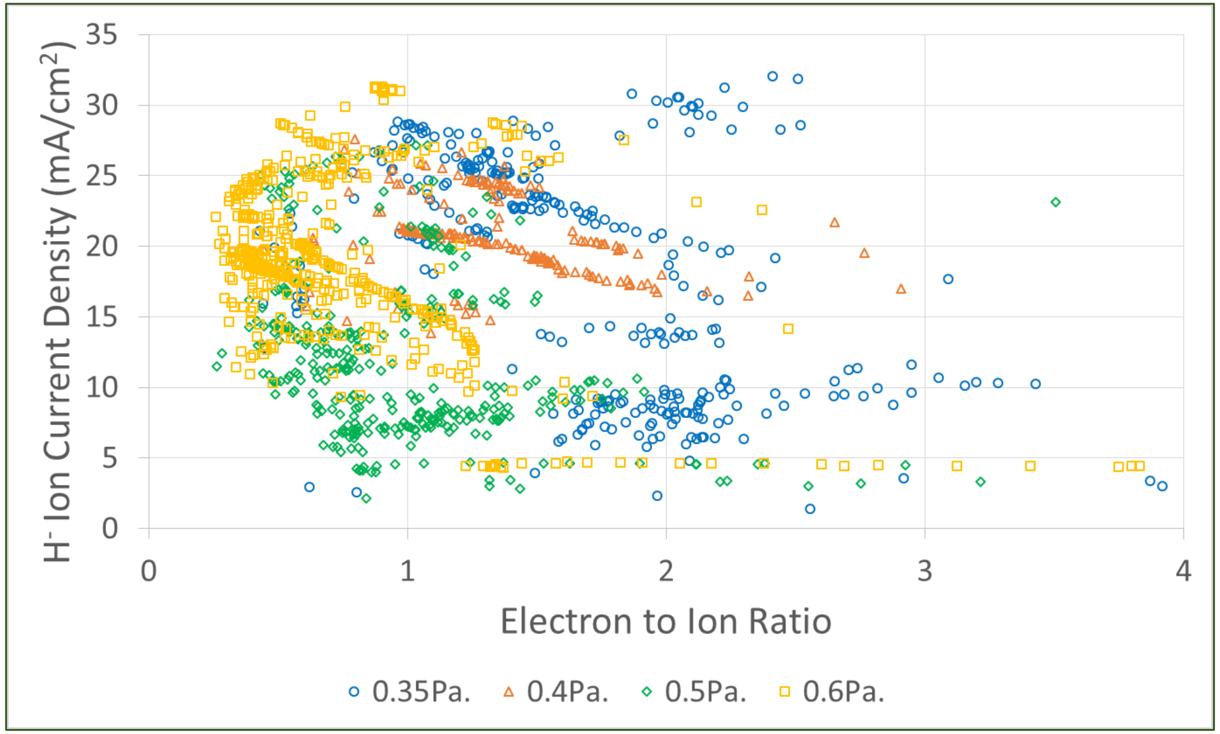


Diameter of the top and bottom rods ~ 8mm and L=250mm

Capability to bias the top, bottom and PG independently

Source performance Summary

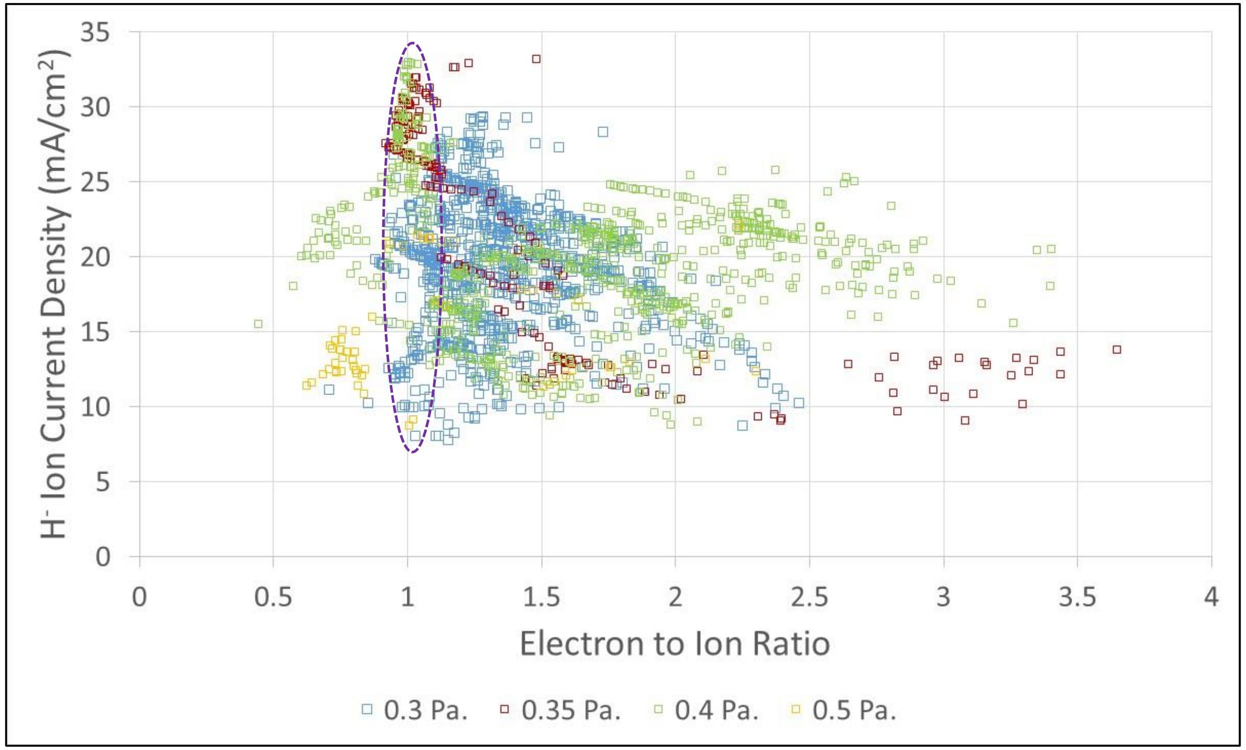
Phase II



Phase III

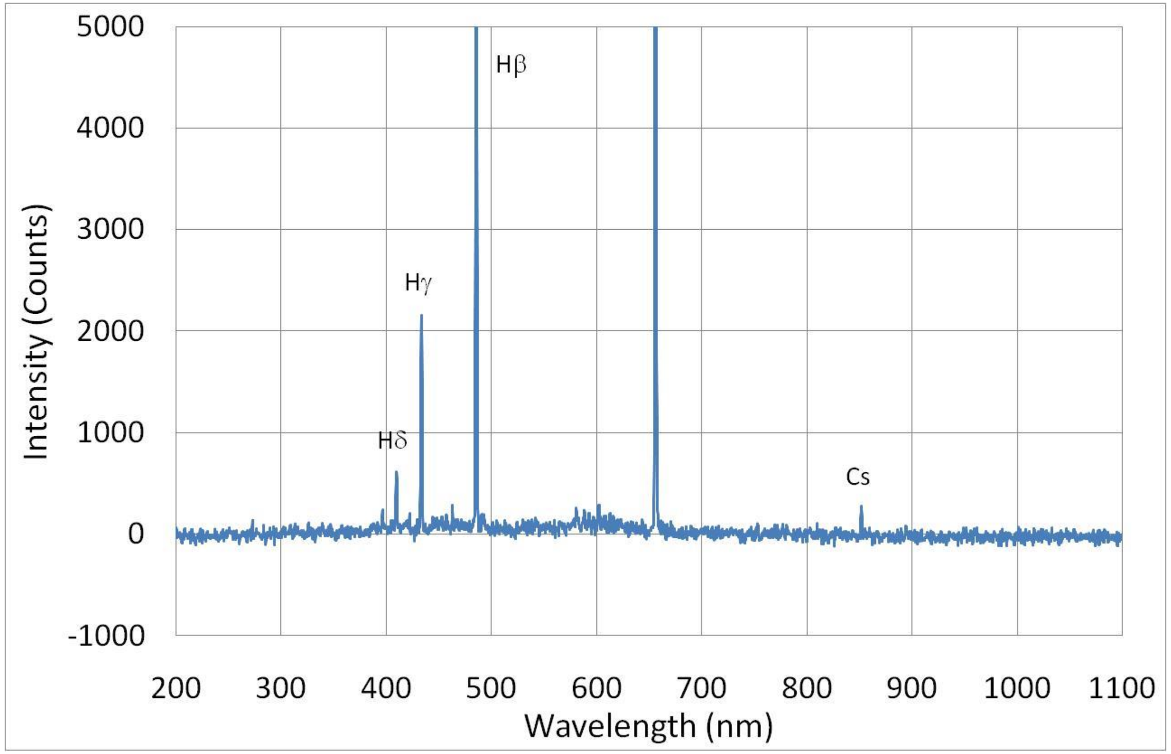
Highlights

- H^- ion current densities > 30 mA/cm^2 for low pressure operation
- Better control on electron to ion ratios at low pressures with the independent biasing of rods and the PG with respect to the source



Impurity comparison ; Phase 1 and Phase 3

Phase - 3

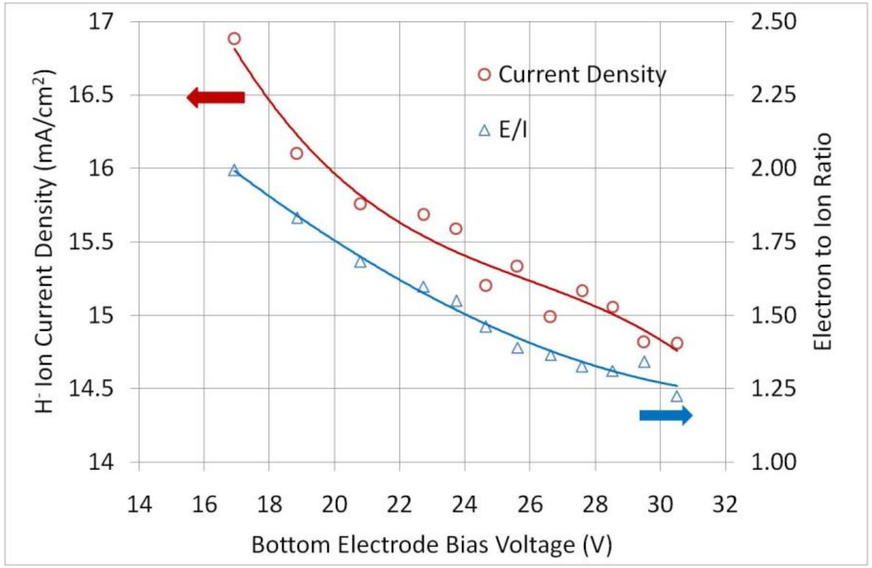


Wavelength	Uncleaned	Cleaned
310 (OH, N2, Cu)	1.7	0.2
777 (Oxygen)	1.4	0.06
845 (Oxygen)	0.3	0.019

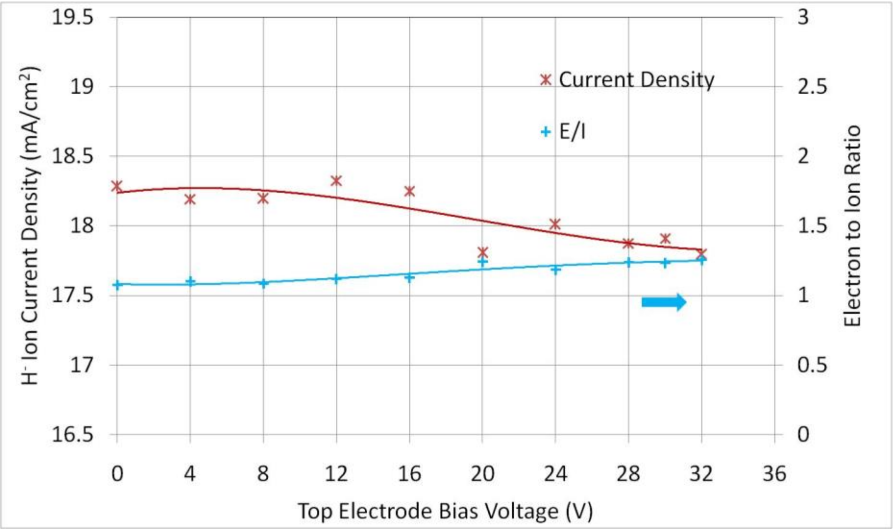
Impurities normalized with H_{δ}

Bias scan with rods and PG bias

Fixed : PG bias:32V Top rod: 32V

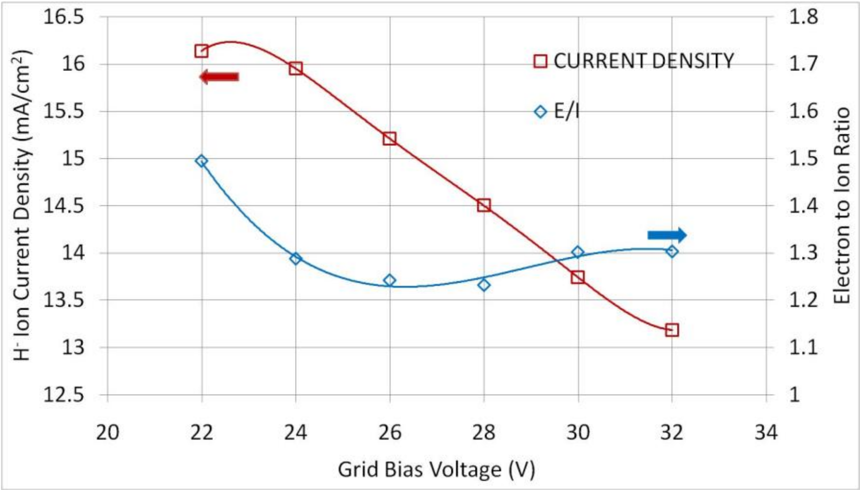


Fixed : PG bias: 24.5V Bottom rod: 32V



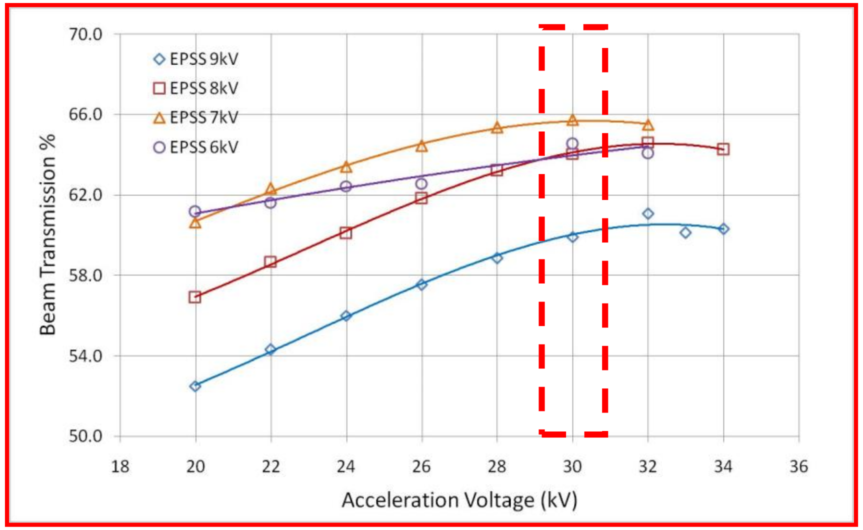
- Top electrode bias is non effective
- Bottom electrode bias is seen to effect the control of electrons severely and has marginal effect on the H- current density
- With optimal bias on bottom electrode, PG bias reduction helps in increasing the H- current density while marginally effecting the electrons

Fixed : Bottom rod: 32V Top rod : 25V

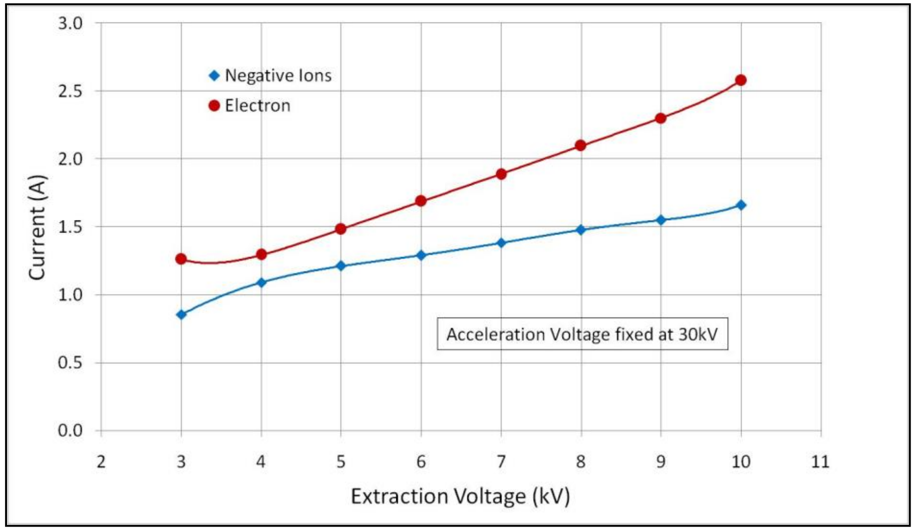


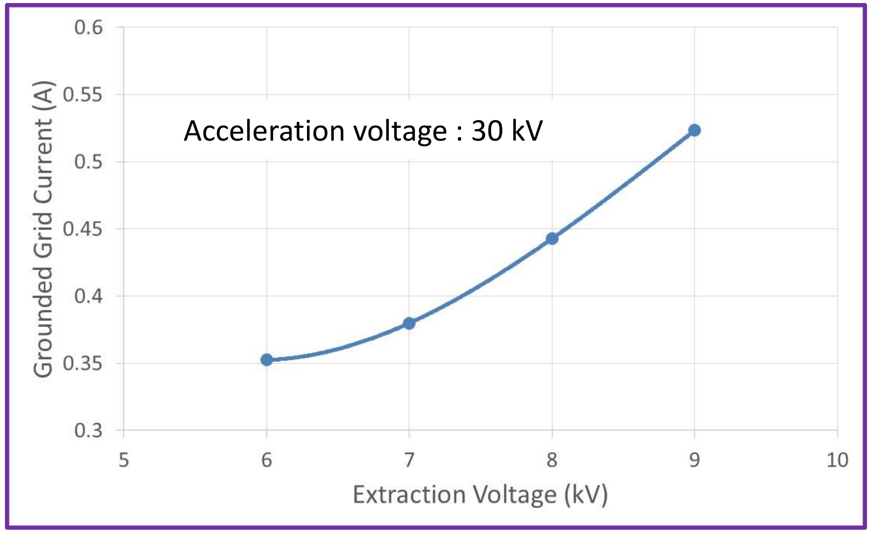
Beam related studies

Acceleration voltage scan



Extraction voltage scan





Summary

Phase I

- H- current density : ~25 mA/cm^2
- Electron/ion ratio very high
- Cs consumption 100 mg/hr
- Lessons learnt : Control on impurities of prime importance

Phase II

- H- current density > 30 mA/cm^2 ; e-/ion ratio < 1 for 0.6 Pa filling pressure
- H- current density > 30 mA/cm^2; e-/ion ratio 2 at 0.35 Pa
- Cs consumption ~ 12 mg/hr
- Better conditioning and control on electrons required for lower filling pressures

Phase III

- Top bottom rods introduced in the source with separate biasing alongwith PG bias
- H- current density > 30 mA/cm^2 ; e-/ion ratio ~ 1 for filling pressures of 0.3-0.4 Pa
- For ROBIN : lower transmission at higher extraction voltages
- Campaign currently underway
- Further analysis to determine H- densities and electron temperatures in the extraction region

Operational experiences to help in beam operations on TWIN and INTF in future

Acknowledgement : IPP Group for continuous support and helpful discussions

Thank you for your kind attention

Supplementary