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Progresses on NIO1 ion source and on energy recovery

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ABSTRACT

- The important task (NBI neutral beam injector for fusion) and the complexity of radiofrequency ion source need large tests (as ELISE and SPIDER) and intermediate scale tests (as NIO1 in this poster) for optimization.
- Conditioning (with gas) was found necessary in Cs-free operation.
- Cs-based operation has begun: stability improves at lower oven temperature; in both cases, lateral view cameras show beam quality.
- Energy recovery plugin almost ready for NIO1 (or at a test station at TRIPS)

INTRODUCTION

$^aH^-$ (with a=1,2,3 understood) ions are fragile (binding energy only 0.76 eV) and difficult to produce; but they are needed for efficient neutral beam injector NBI (to make fusion work).

+The 'Two rule': H- ion sources must have <u>two</u> plasma regions (separated by filter B^s) at different temperatures: driver (electron temperature T_e >4 eV to dissociate H_2) and extraction (Te < 2 eV, to store the fregile H- before extraction); <u>two</u> species are extracted (H- and unwanted electrons) so a deflection field B^d is needed after extraction. With z the extraction axis, B^d is mainly along y; optimal B^s is crossed (ie, along x).

+NIO1 has multipole confinement, solid state rf generator, 7 turns rf coil (relatively long), and can work CW for hours (cryo on) or days (cryo off)

+NIO1 design compensates x deflection (CAM2) with ADCM; y deflection (seen by CAM1) due to B^s_x has PM (permanent magnet) terms (short range) and current I_{pg} effects (larger range);

- Rf generator is not self-resonating, with a short transmission line; NIO1 resonance depend on gas (from 2010 to 2014 kHz for vacuum, light gases, 2025 kHz for Ar, 2035 kHz for Xe, 2060 kHz for Ar cleaning after Cs);
- NIO1 rf driver work even at large filter fields (12 mT); trend of optimum value is $|B^s_x|$=11 mT for Cs-free regime and ≤ 7 mT for Cs regime (no I_{pg}).

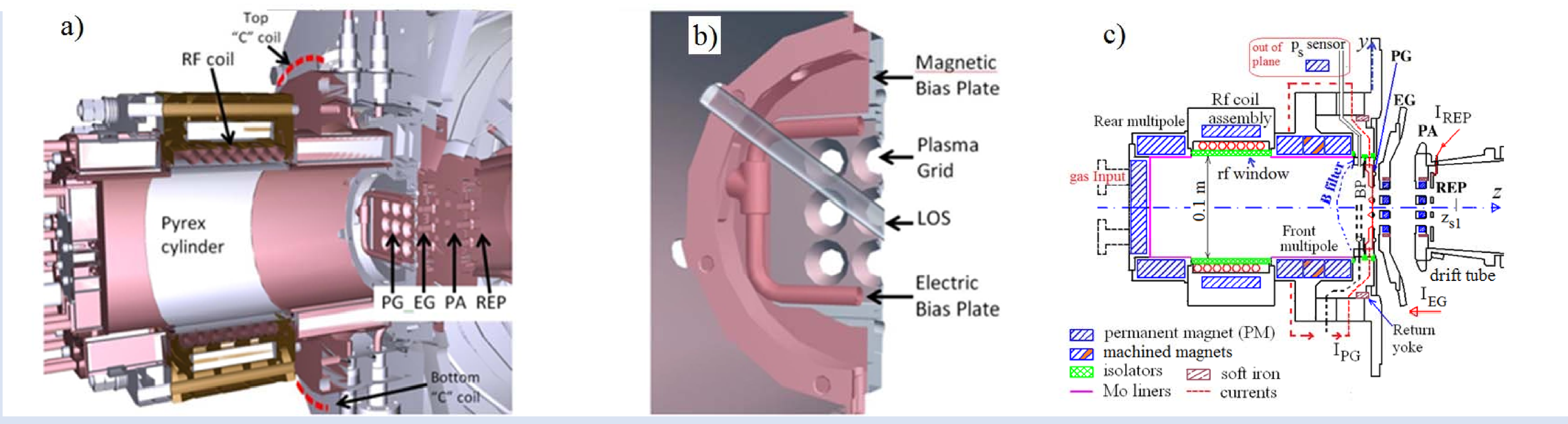


Fig. 1. a) Cut view of NIO1 plasma chamber and grids (see labels); b) detail extraction view and line of sight (LOS); c) NIO1 yz section: note extensive permanent magnet installation and the proportions of driver and source parts.

THE DISCOVERY OF GAS CONDITIONING (in Cs-free regime)

TRANSIENTS

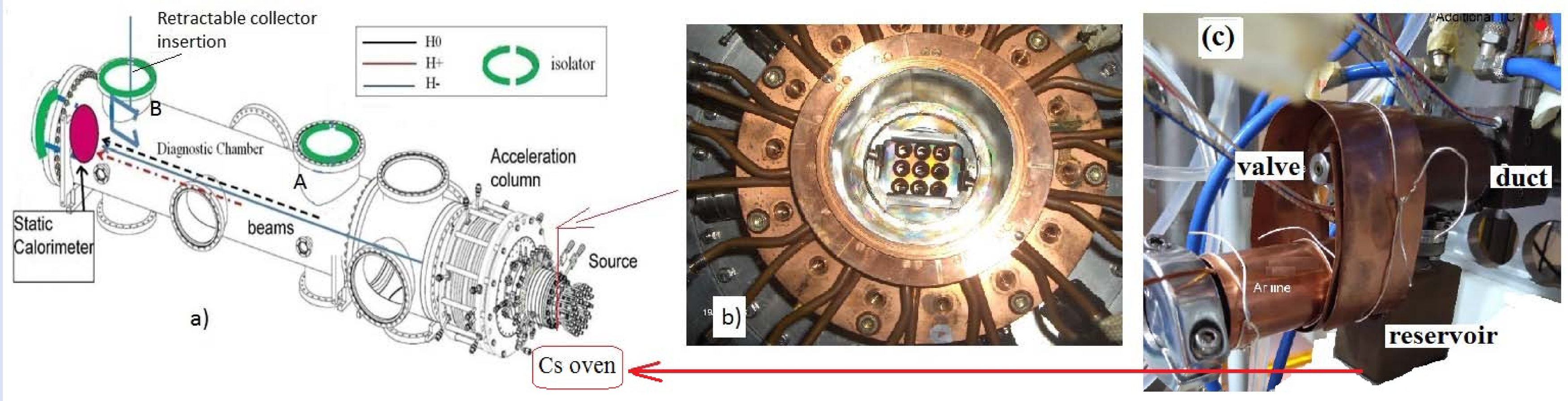
NIO1 can maintain stable plasma input condition (H_2 pressure, rf forward power P_k) at least for one working day and cryo operation for two hours (more cryo purchased): but plasma multistability may produce transient (on 10 minutes scale) with the correlation: more luminosity/less H- production.

WAYS TO STABILIZE THE DARKER and MORE PROLIFIC PLASMAS:

1) To cool rf window; 2) To condition surface with oxygen (ICIS2019), or N_2 or Ar or Xe (this conference). Working hypothesis: the more electrons from walls, the denser and cooler the plasma, the better the H^- survival.

WHAT NEXT (hopefully)

1) Faraday shield built by additive method (AM) and rf simulation of driver; 2) rf system experiment: worsen transmission line/generator to help new source design (DTT, Demo); 3) enlarge bias plate BP aperture.



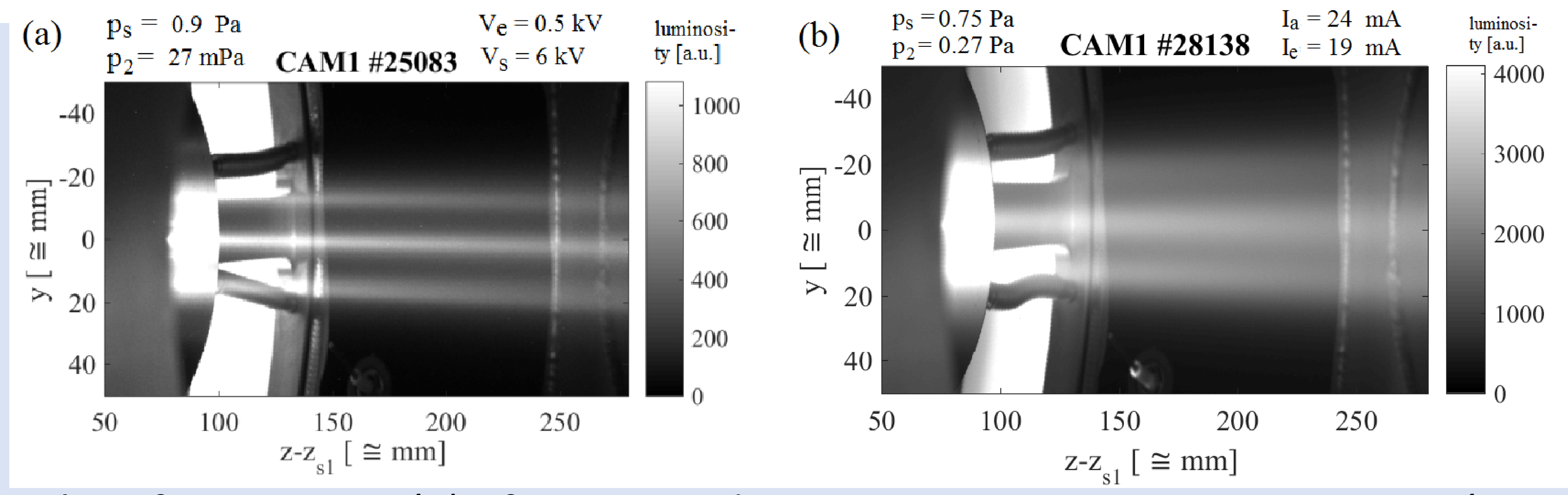
(a) 3D overview of NIO1 (b) cut view of source, looking towards plasma grid; (c) view of Cs oven, placed below ion source as shown

THE 1st Cs oven results and possible improvements

+ 1ST Cs oven has a reservoir (held at temperature T_{res}, a valve and a pipe, independently heated); temperature T_{inlet} is also measured at NIO1/oven connection, and temperature T_{end} (Cs nozzle) is calculated by simulation; oven has to be covered by strong thermal insulation to work properly (to avoid colder points).

+After several oven and installation debug, beam current I_a increase by a factor two (up j_{H-} ≈ 40-50 A/m²) were obtained at total voltage V_s=11 kV (and extraction voltage V_e =1.2 kV) with 12 hours heating at moderated T_{res} <190 C. Heating more (T_{res} = 240 C) did decrease extracted electrons j_e, but with no further j_{H-} improvement.

⟹Cs dynamics need patience, no humidity, better wall heating and a better Cs nozzle (see paper).



Samples of CAM1 view (a) after N2 conditioning, I_{pg}=400 A, I_a=3 mA, cryo on (source pressure p_s and accelator one p_2 as label); (b) with Cs, I_{pg} =10 A, V_s=10 kV, V_e=1.1 kV.

Energy recovery

ACCELERATOR BASIC

Efficient energy recovery requires mastering huge perveances $P=I/(Ki/e)^{1.5}$ in the collector. Also free electron lasers uses electron energy recovery.

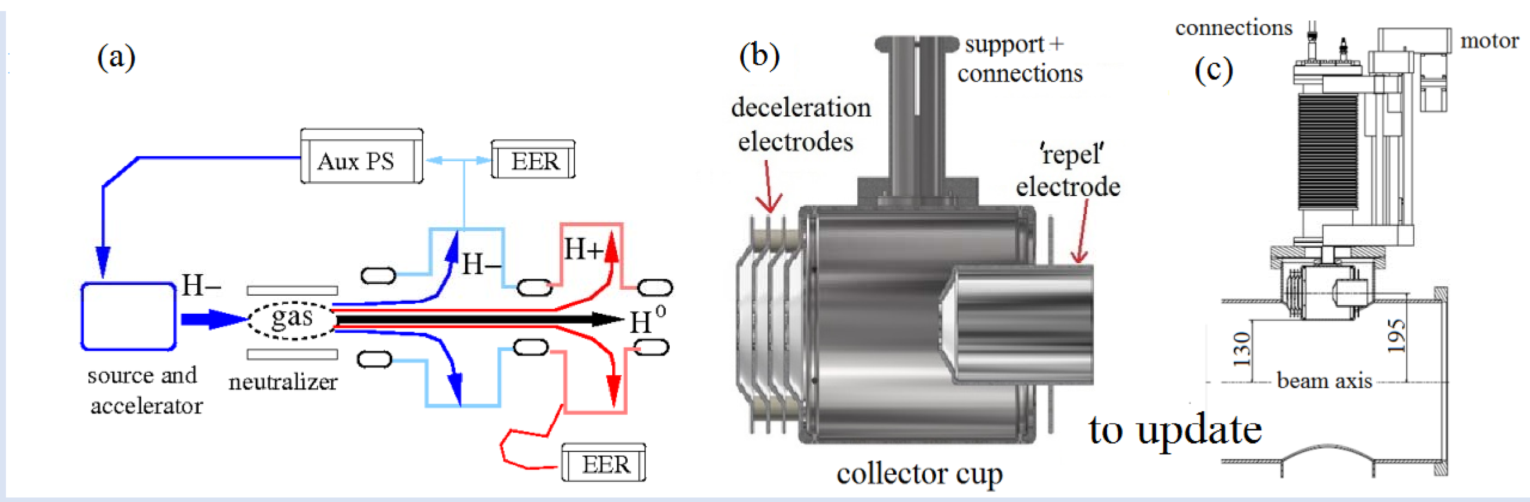
SPACE CHARGE ASSISTED PARTICLE COLLECTION

+We use perveance to deflect particle: larger efficiencies possible.

+We use charge recirculation to simplify electronics (otherwise you have to make an inverse inverter EER to convert 100 kV to main).

+Secondary e⁻ emission is depressed by geometry and large efficiency.

+Simulation including energy spread are challenging (no laminar beam).



a) concept of energy recover: EER are electronic energy recovery units, Aux PS is a low voltage auxiliary power supply; (b) a plugin for NIO1 or TRIPS; (c) plugin movement.

CONCLUSION

The large database and time span of NIO1 dataset helped to recognize complex phenomena in H⁻ ion sources, including filter magnet and radiofrequency tuning: 1) conditioning gases (idea evolving from air conditioning effect) was detailed; 2) The Cs oven installation and first experiments were described; 3) some notes on Cs dynamics (and possible oven improvements in the manuscript); 4) Evolution of energy recovery setup is also reported.

ACKNOWLEDGEMENTS / REFERENCES

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