The H^- multiaperture source NIO1: gas conditioning and first cesiations

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poster at Int. Conf. Ion Sources
21 Sept. 2021, abstact ID: 6

ABSTRACT

- In NIO1 (Negative Ion Optimization step 1), a H^- ion source installed at RFX operated in continuous mode, gas conditioning was needed to improve H^- current density j_i (up to 30 A/m^2) in Cs-free regimes,
- Installation of a cesium oven gave a larger increase of current (with a peak of 67 A/m^2). progressively limited also by a rapid overcesiation
- Other limiting factors may be: a narrow bias plate mask (now enlarged); mismatch between current density and applied voltage, as shown by here reported new simulations, instability of good conditions
- Further improvements for Cs-based regime include a moderate oven reservoir temperature, careful tuning and a substantial increase of beam voltage, and power handling capability

INTRODUCTION

- Large D- ion sources [1-4] are required for neutral beam injectors; ion current density j_i must be > 200 A/m^2, with electron current density j_e as low as possible (so that $R_j=j_e/j_i<1$) and pulse duration > 3600 s. For H^- case, in Cs-based regimes j_i = 300 A/m^2 and R_j<1 are feasible. In Cs-free regimes, j_i = 30 A/m^2 and R_j=10 is expected.
- The NIO1 **can be operated in continuous mode** (only H, no D for safety), so transients are easily evidenced: to stabilize them, the so-called 'gas conditioning' was developed (one day of a gas like Xe or O_2, few days of stable H^- production). In Cs-free regime j_i about 25 to 30 A/m^2 (with beam voltage V_{ag}=11 kV) and R_j < 5 was reached.
- From 2020 a Cs oven was installed, obtaining j_i up to 67 A/m^2 and R_j<0.5 for a while; then j_i rapidly decreased for overcesiation
- NIO1 design compensates x deflection (seen by CAM2) with ADCM [5,6]; y deflection (uncompensated) is seen by CAM1 (and CAM3).
- A large filter field can be provided in NIO1; optimum value is $|B^s_x|$=11 mT for Cs-free regime and ≤ 7 mT for Cs-based regime

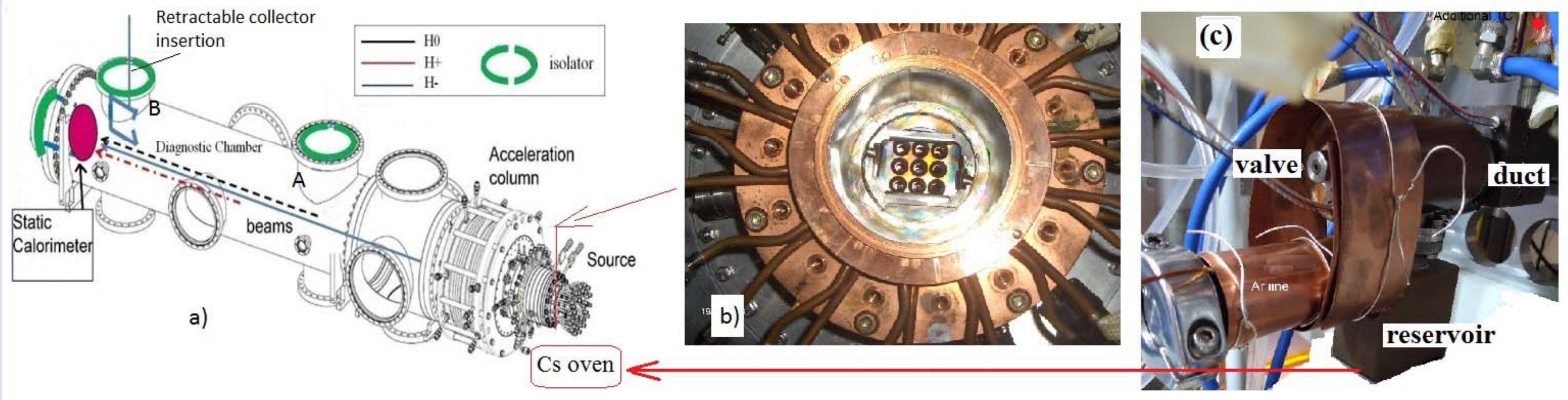

Fig 1 (a) 3D overview of NIO1, z is the beam axis, x is the vertical (b) cut view of source, looking towards plasma grid; (c) view of Cs oven, placed below ion source

SETUP

ELECTRONICS and CURRENTS

NIO1 has two bias systems and several power supplies (PS; ion current I_a is estimated as the output I_{ag} of the V_{ag} PS (also called AGPS) minus known leakages $I_a=I_{ag}-V_{ag}/R_t$ (see fig 2 b); electron current I_e is the output of extraction grid PS (or EGPS). Then $j_i=I_a/A_e$ and $j_e=I_e/A_e$ with area A_e=410 mm^2. Calorimetric current I_{cal} and current I_{cfc} on CFC (carbon fiber composite) tile may be also recorded, observing $I_{cal}<I_a<I_{cfc}$

SOURCE/BEAM OPTICAL DIAGNOSTICS

- Plasma light intensity measurements (monitoring of plasma conditions)
- High resolution Spectroscopy (impurities, Balmer series, Fulcher band, Cs I emission); also Low resolution Spectroscopy
- Laser Absorption Spectroscopy (neutral Cs density)
- Cavity Ringdown Spectroscopy (H^- density, in preparation)
- Lateral visible cameras (beam deflection and divergence)
- Beam emission spectroscopy (deflection, divergence, stripping losses)
- calorimetry on CFC target (beam deflection and divergence, beam current)

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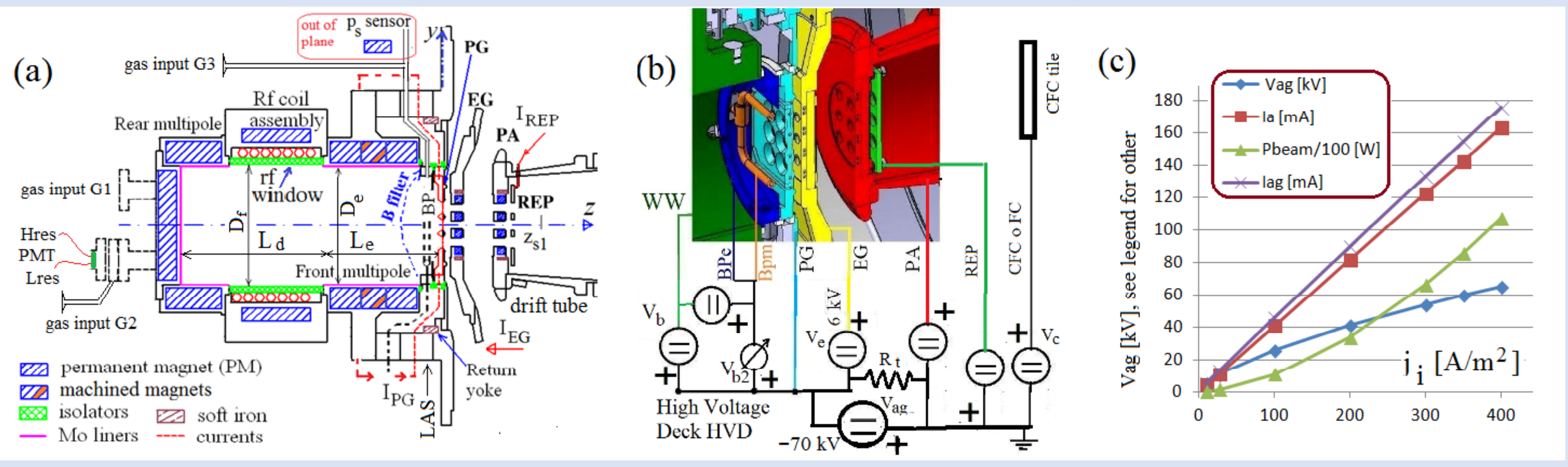

Fig. 2 (a) NIO1 main section; note that High Resolution (Hres) and Low Resolution (Lres) spectrometer fibers are multiplexed a CF16 port, where also a second gas input G2 is provided; photomultiplier (PMT) is placed on a CF16 port below; (b) scheme of power supplies (see also Figs. 2 and 4.a in Ref[10]; (c) scaling of voltage and power on electrodes EG and PA vs j_i

SIMULATIONS

Based on empirical emission model[11], with user guessed parameters for initial energy =3eV; fast to run; similar [8,10] or more complete model [9] exist. With voltage assumed in Fig 3, only j_i <30 A/m^2 is fully transported.

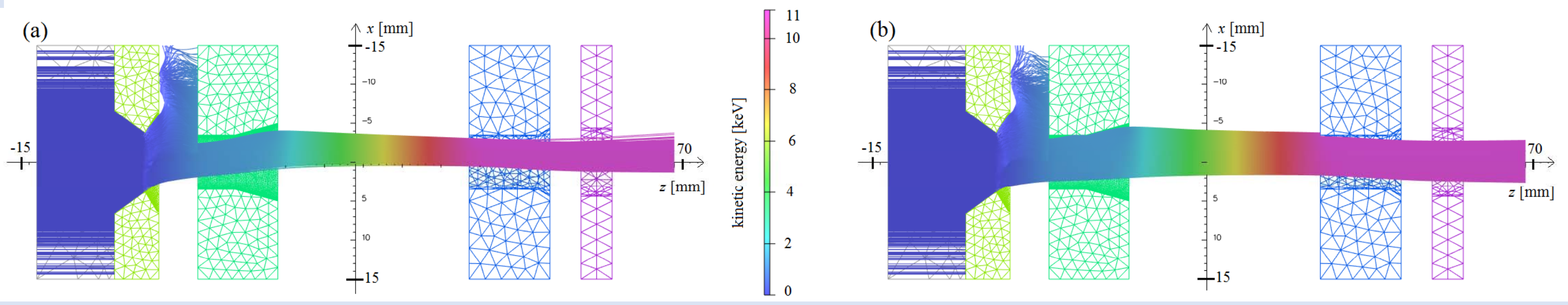

Fig 3. (a) xz projection of electrode wireframe and simulated beams (e^-, H^-) with j_i= 25 A/m^2, R_j=5, V_{ag}=11 kV, V_e=1.3 kV. (b) as 'a', with j_i= 35 A/m^2

SELECTED RESULTS and IMPROVEMENTS under test

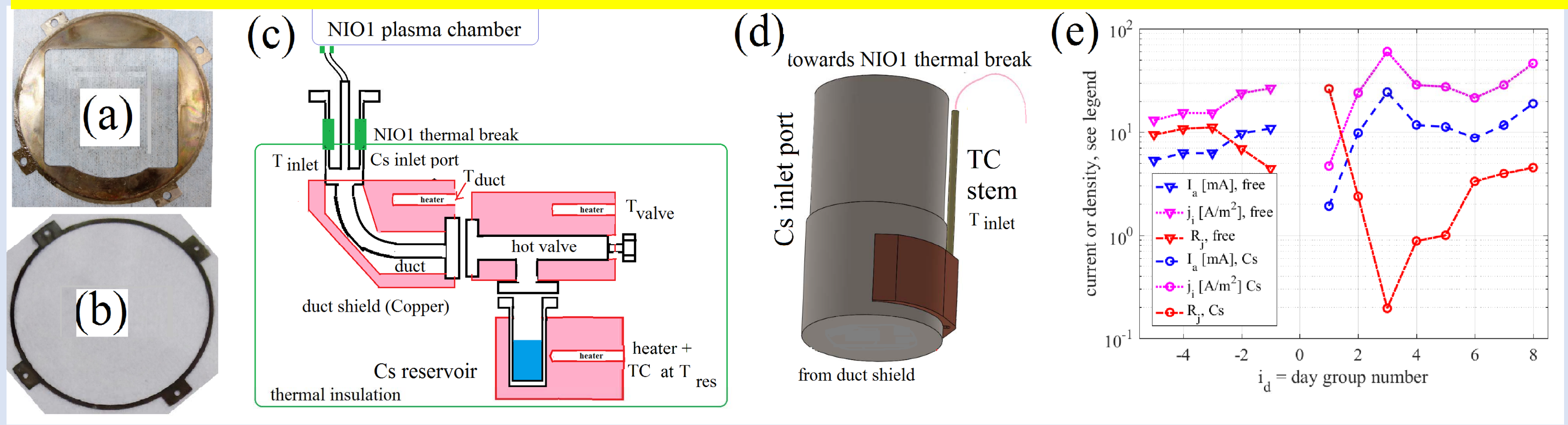

Fig 4: (a) old BP mask (b) new BP mask; (c) Scheme of Cs oven, heaters and TCs placement with detail: (d) 3D view of TC inlet clamp; (e) Comparison of 2019 Cs-free results i_d<0 (id=-4,-3,-2,-1 are conditioning respectively with Ar, N_2, O_2 and Xe) and 2020 Cs-based results, where i_d enumerates the result group (each group contains one or more days)

- The peak j_i ≈ 65 A/m^2 was obtained for few h in i_d=3 group (one day), see Fig 4.e
- Oven temperature T_{res} (fig 4.c) should be much moderate (<400 K, to be tested soon): tighter thermocouple connections (4.d) are progressively mounted for better control;
- The bias plate mask (4.a) is now enlarged (4.b) to allow more plasma in the extraction;
- At high current, optics seems more difficult (need more tuning time and voltage), but less beam y-deflection appears

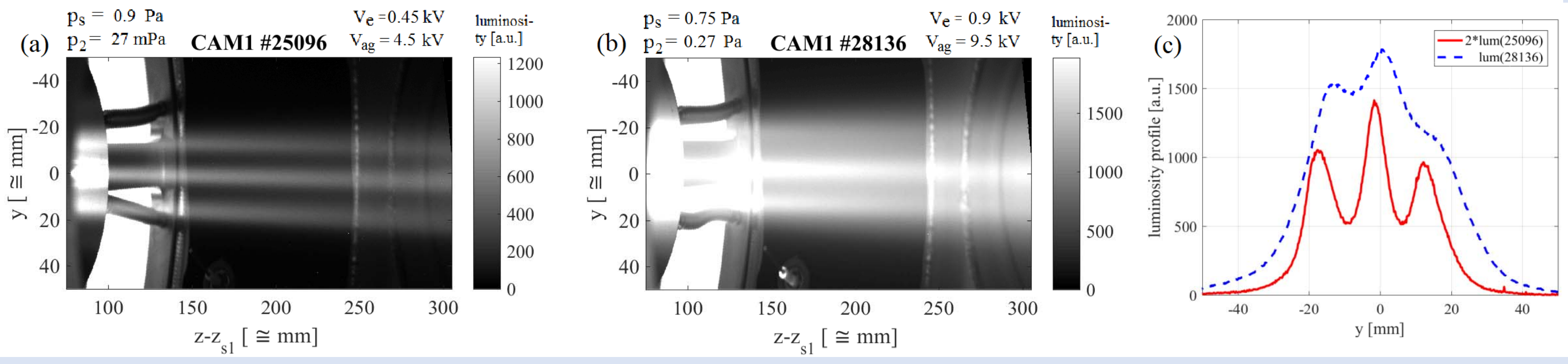

Fig 5 (a) Typical Cs-free optics, at cryopump on, Ia=1.6 mA, before O2 and Xe conditioning (dataset 25096, CAM1); (b) Cs-based optics, cryopump off, I_a=19 mA, I_e= 11 mA (dataset 28136, CAM1); (c) profile comparison.

CONCLUSIONS

The large database of NIO1 dataset helped to recognize complex phenomena in H^- ion sources, including filter magnet and radiofrequency tuning: 1) for Cs-free conditioning gas was discovered; 2) For Cs-based regime, some indication of optimal temperature was given; 3) beam optics is better understood

ACKNOWLEDGEMENTS

Work set up in collaboration and financial support of INFN (project INFN-E and Group 5, Exper. Ion2neutral) and EUROFusion. This work has been carried out within the framework of the EUROfusion Consortium and Euratom research and training programmes under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. See manuscript for details; bibliography on the left