Emissive Electrode Plasma Biasing Experiments on Tokamak ISTTOK

INSTITUTO SUPERIOR TÉCNICO
Centro de Fusão Nuclear

H. Figueiredo, C. Silva, I.S. Nedzelskiy, C.A.F. Varandas, J.A.C. Cabral
Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico, 1049-001 Lisboa, Portugal

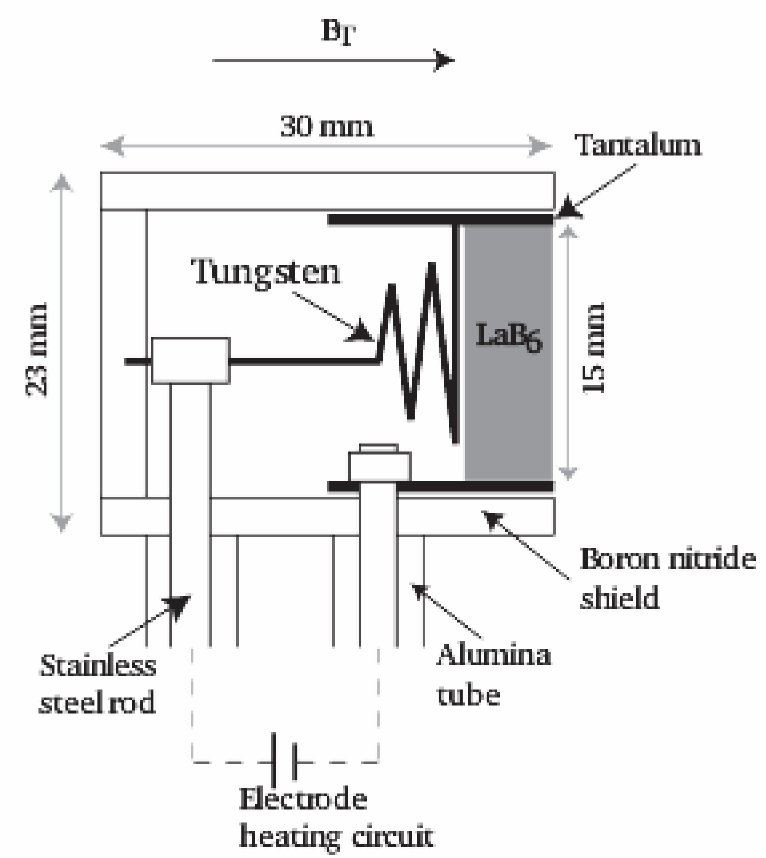
R.M.O. Galvão
Instituto de Física, Universidade de São Paulo, São Paulo, Brazil

Motivation

- Aiming the modification of the radial electric field in plasma devices
  - biasing of plasma facing components like limiters
  - Biasing of electrodes inserted into edge plasma
- For negative bias the current drawn standard electrodes is not enough to decrease the plasma potential due to limitation by ion saturation current
- Emissive electrodes produce a much larger current, therefore allowing a more efficient way to control the edge radial electric field
- Previous use of emissive electrodes attempted in Macrortor, CCT, HYBTOK-II, MST

Emissive Electrode Design

- The emissive electrode is made of lanthanum hexaboride (LaB6)
  - high (2210° C) melting point
  - low vapor pressure
  - chemical stability
  - Electron emission up to 20 A/cm^2
  - Operating temperature of LaB6 emitters ranges from 1700 to 1900° C
  - LaB6 disk with a diameter of 18 mm and 2 mm thickness;
  - tantalum cylinder protected by boron nitride cup as insulating material to be exposed into the plasma;
  - tungsten filament of 0.5 mm diameter arranged inside the tantalum cylinder for heating;
  - the whole dimension of the EE is 23×23×30 mm3

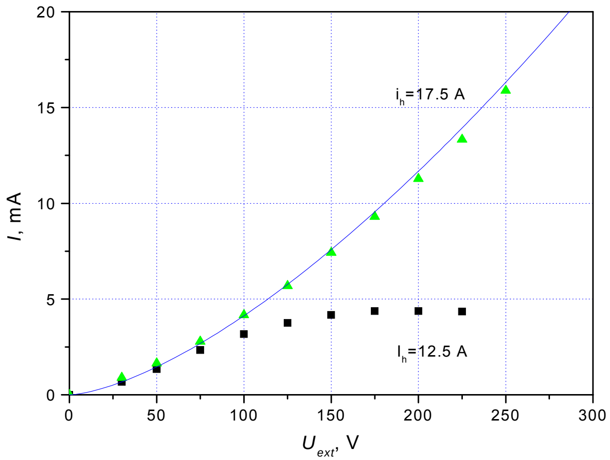


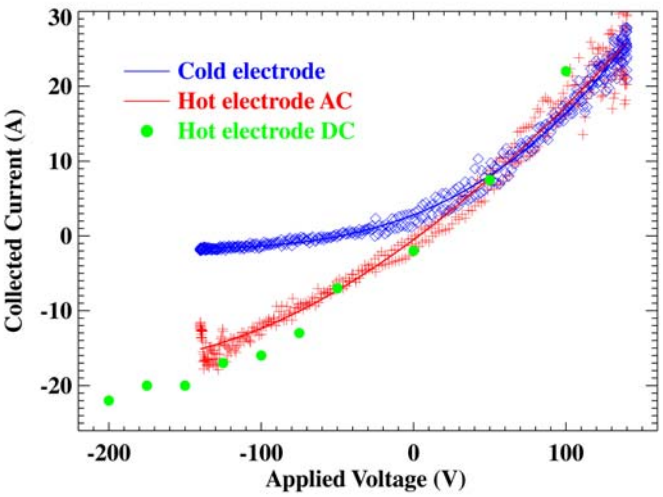
Emissive Electrode I-V characteristics

- For a heating current of 12.5 A, a saturation of the emitted current is observed due to restriction by low cathode temperature.

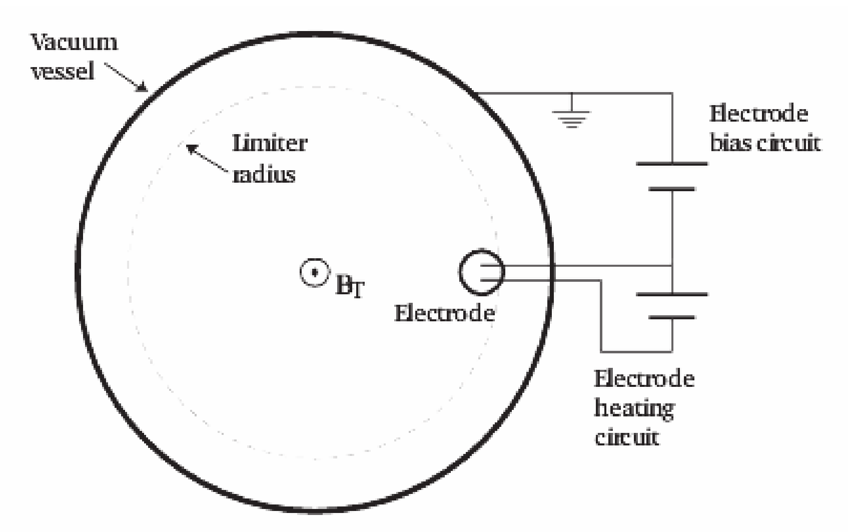
- At heating current 17.5 A, the experimental results follow the Child-Langmuir law for the space-charge-limited current

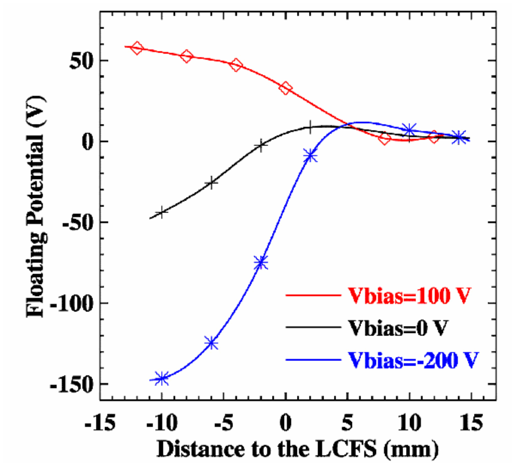
- The dependence of the emitted current in plasma (which is the difference between the currents of hot and cold electrode) is clearly different from that in the diode configuration: the current value is much larger, and a tendency to saturation is observed.

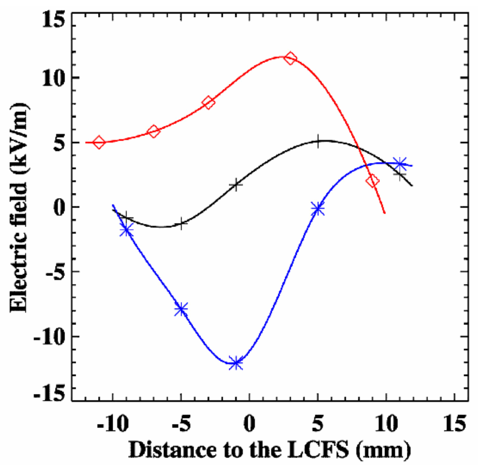




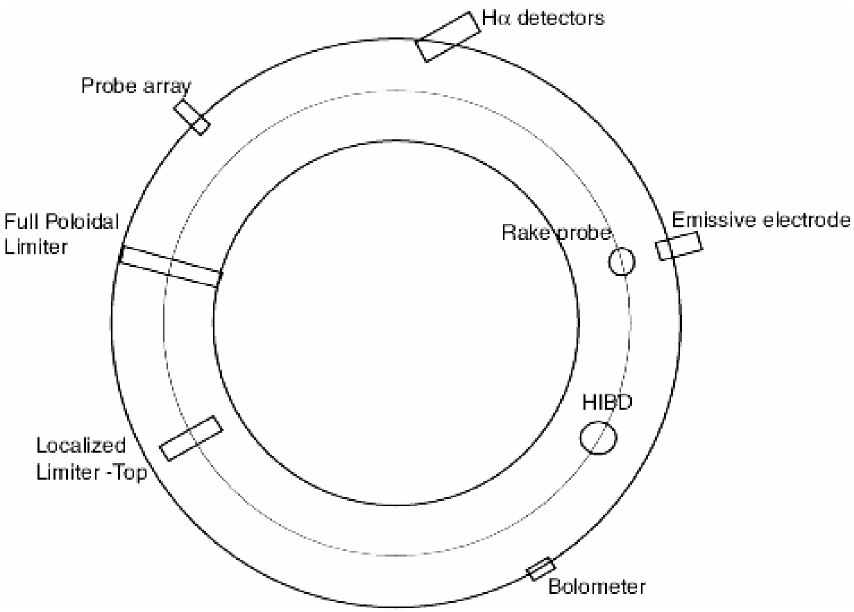
Electrical Circuit and efectiveness of EE biasing







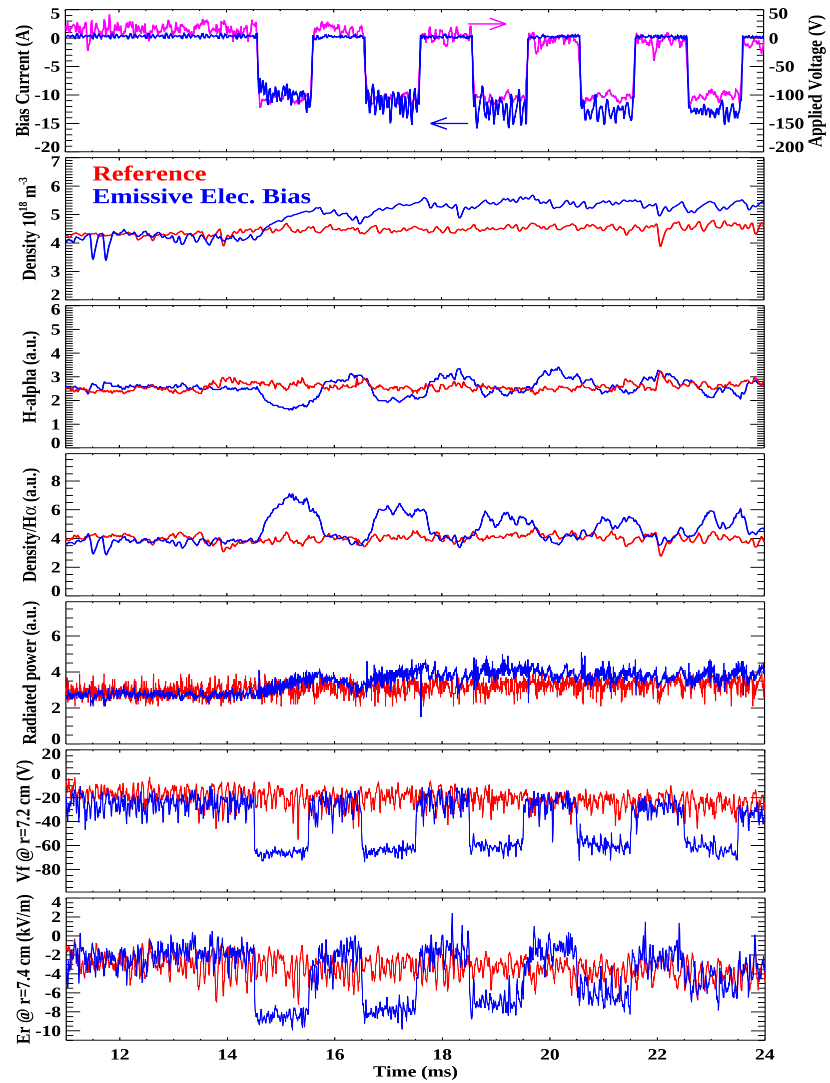
Experimental Setup



- ISTTOK is a large aspect ratio circular cross-section tokamak
  - R = 46 cm, a = 7.8 cm, B_T = 0.5 T, $\Delta\Phi$ = 0.22 Vs
  - fully poloidal graphite limiter at r = 7.8 cm
  - Movable small stainless steel localized limiter consisting of a section of a poloidal limiter
- Typical values of the ISTTOK discharge parameters:
- Ip ≈ 5-6 kA, Δ t ≈ 30-40 ms, $n_e(0) \approx 5\text{-}10\times10^{18}$ m^{-3}, $T_e(0) \approx 150\text{-}200$ eV, $t_p \sim 0.5$ ms, β ~ 0.5 % and edge safety factor q(a) ≈ 5.

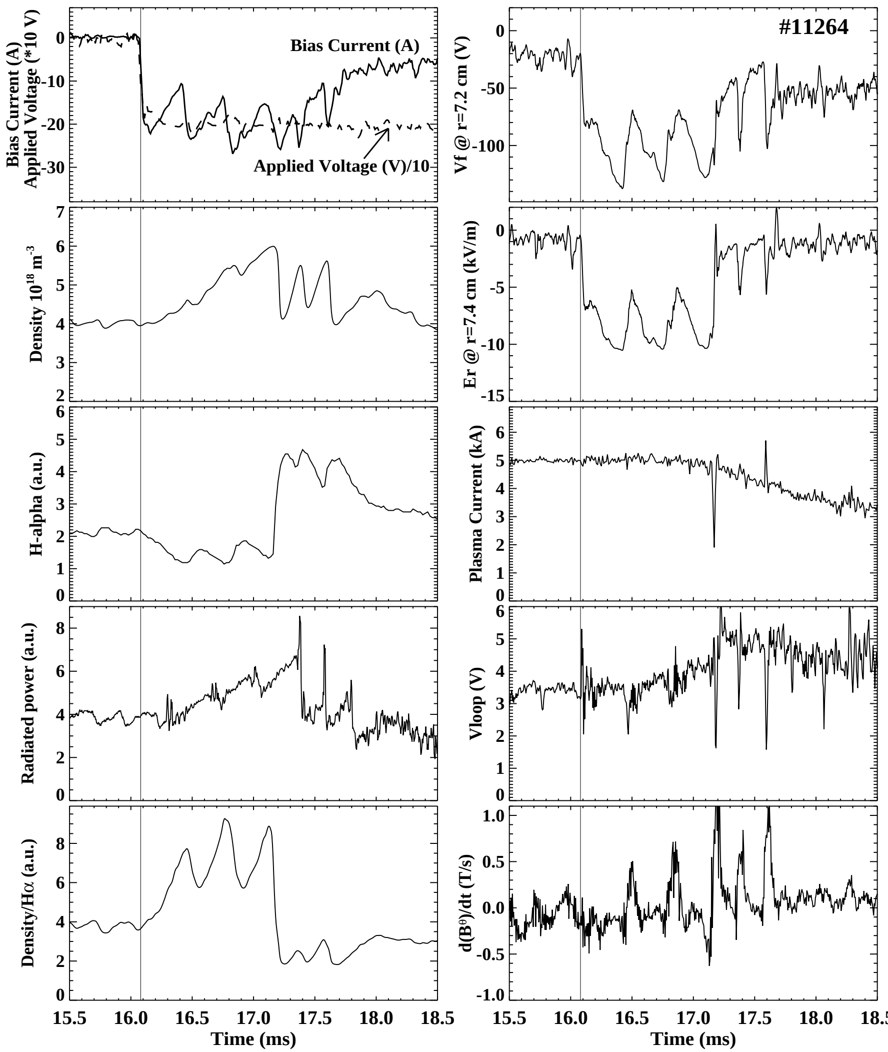
Discharge behaviour with negative EE bias

- For low values of the bias current (V_{bias}= -100 V, $|I_{bias}|$ < 15 A), 12 mm inserted into LCFS
  - I_{bias} >> (I_{sat} ~ 1A)
  - n_e increases and the H_α decreases during the polarization pulses
  - P_{rad} does not increase appreciably
  - V_f drops about 40 V
  - n_e rises with t ~ 0.5 ms. After bias pulse falls off with a larger time
  - Steady state at larger n_e after third pulse

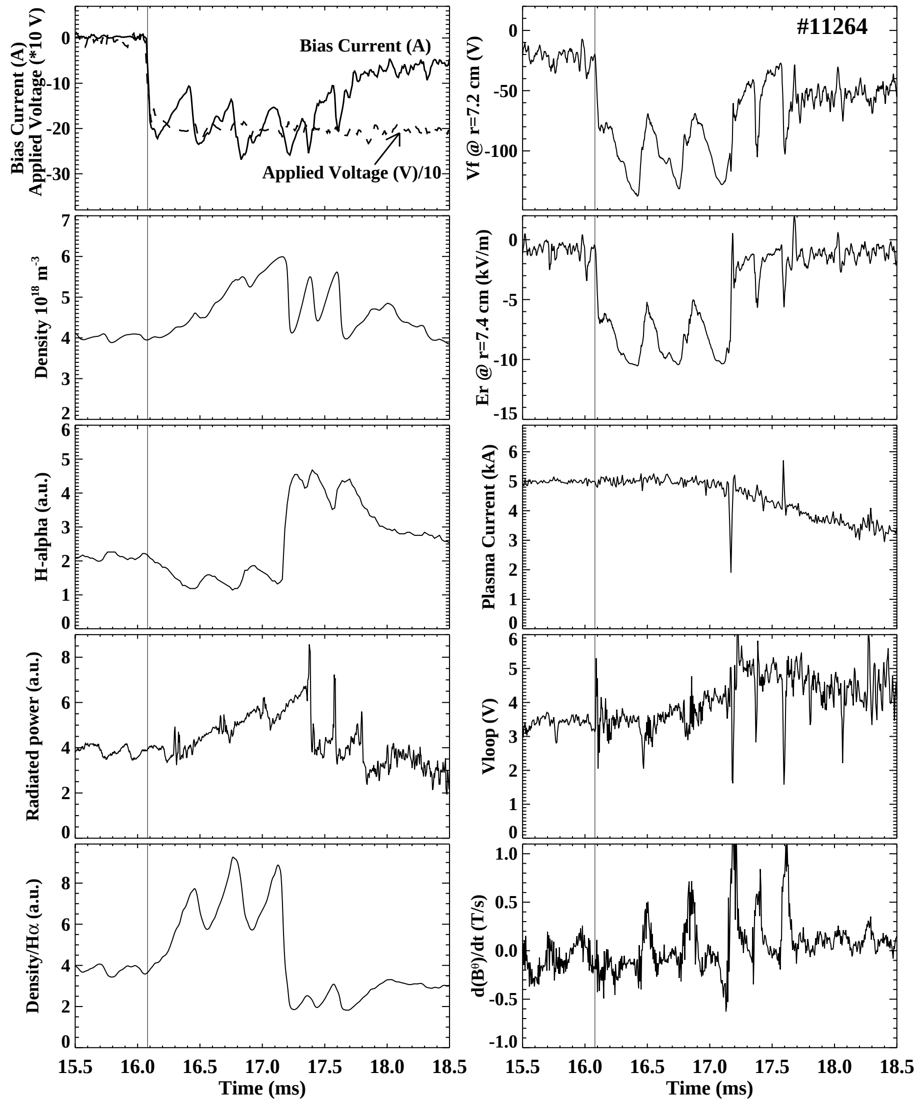


Negative EE bias at large emission current

- V_{bias}= -200 V, $|I_{bias}|$ ~ 25 A, 12 mm inserted into LCFS
  - V_f drops rapidly about 60 V at r-a = -6 mm, while it does not change significantly close to the limiter.
  - E_r increases from -1 to -7 kVm^{-1} just inside the limiter
  - n_e increases ~50%
  - H_α decreases ~40%
  - P_{rad} increases (?)

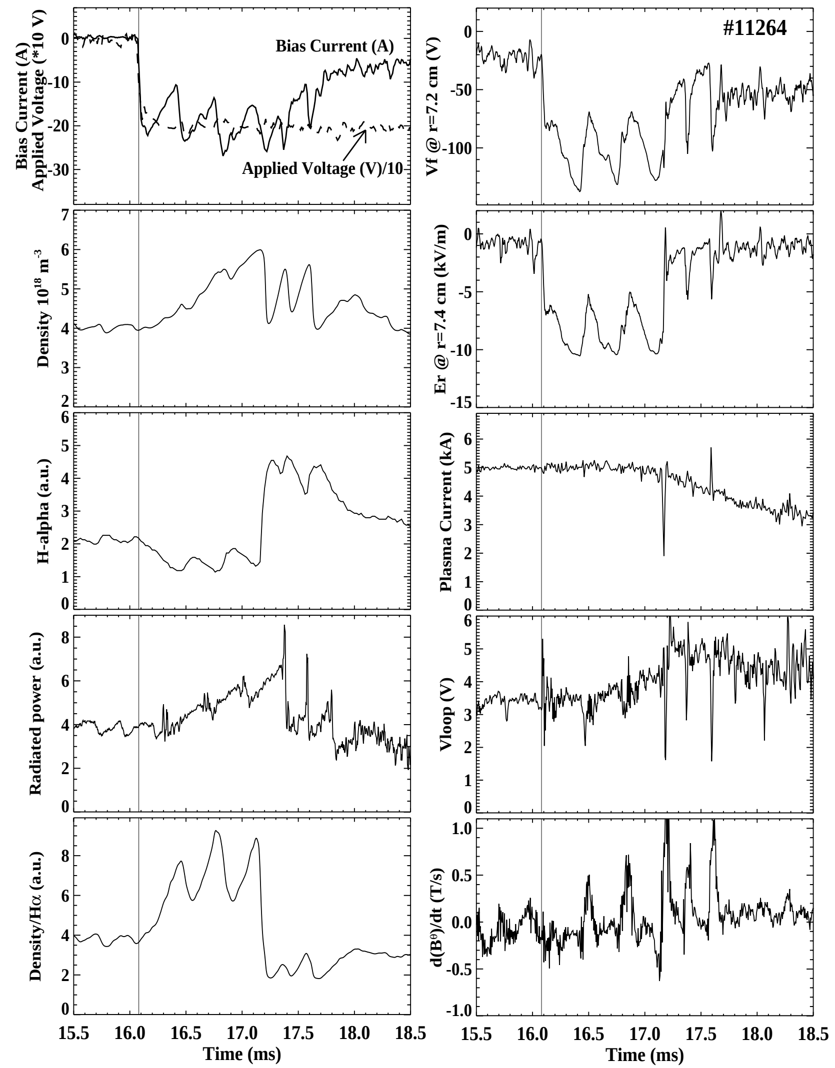


- End of the improved confinement period (t ≈ 17.5 ms). Fast perturbations in the plasma current, Vloop and Mirnov coils signals
- Current collected by the electrode modifies significantly the edge current profile and may have detrimental effects on the MHD stability (Kesner et al)
  - positive current at the plasma edge has a destabilizing effect
  - negative edge current is expected to improve plasma MHD stability
- Vloop and Mirnov coils signals during the periodic degradations in confinement probably result from a modification in the plasma transport properties

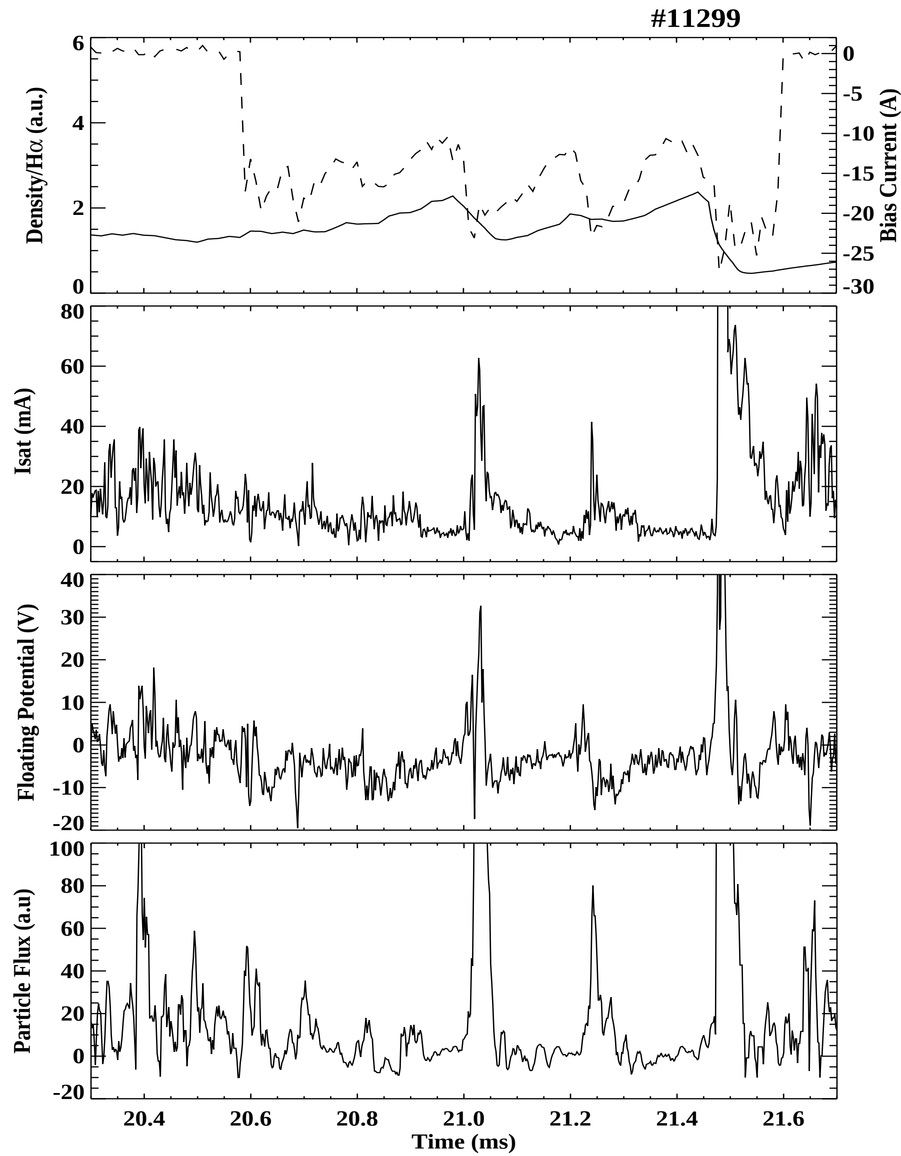


Improved Confinement Events (ICEs)

- Require a minimum bias current (> 20 A) and are characterized by:
  - Increased radial electric field (or a modification of its profile)
  - reduction in the amplitude of the collected current
  - strong increase in particle confinement
- In most of the discharges, we observe no more than two or three consecutive cycles of ICEs
- Good confinement properties of the plasma are periodically lost
  - reduction in density and radiation losses
  - rise in Hα radiation intensity
  - fast increase of the collected current amplitude, associated with reduction of the edge radial electric field
  - sharp increase of both the turbulent particle flux and the density near the limiter

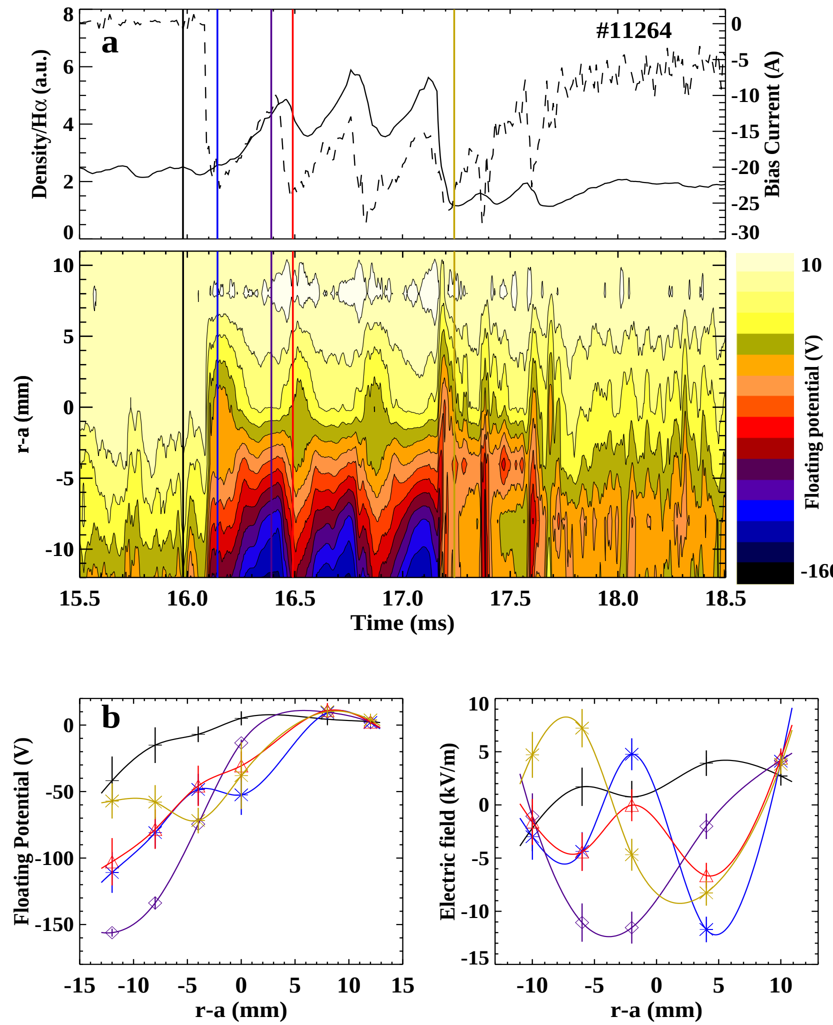


- V_{bias}= -175 V applied at 20.6 ms for 2 ms
  - Average turbulent transport is reduced after the bias is applied, decreasing periodically during each ICE
  - I_{sat} and V_f fluctuation levels are reduced by a factor of ~2 when negative EEB is applied.
  - I_{sat} fluctuation level is reduced 10 times during ICEs
- Observations are consistent with a local reduction of the anomalous particle flux, as a result of a reduced electrostatic turbulence

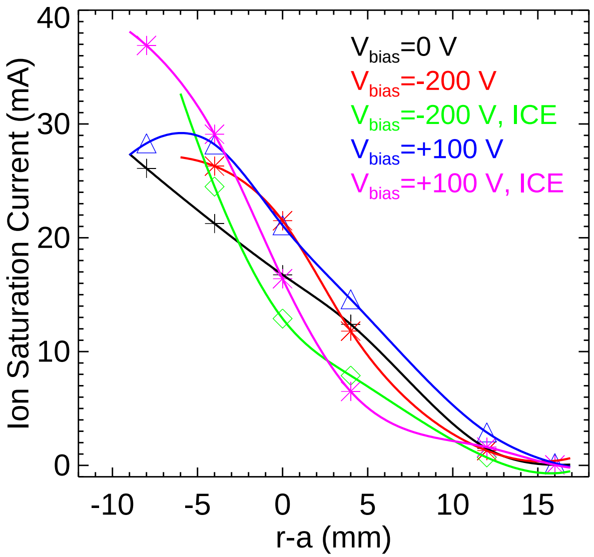


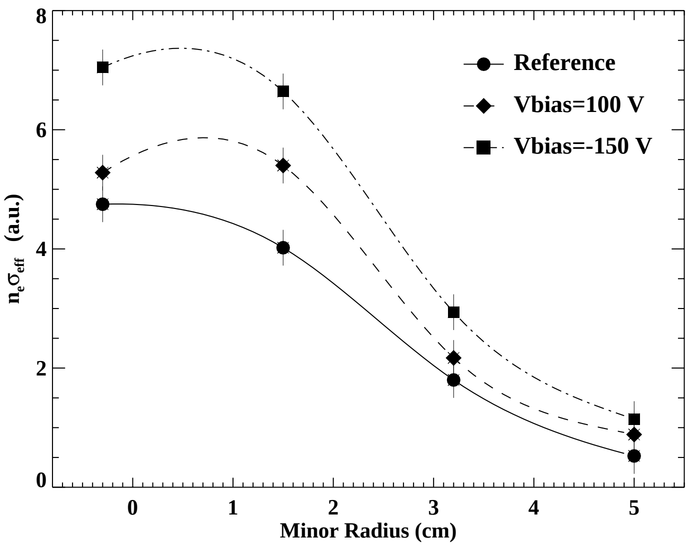
Evolution of the radial plasma profiles

- As the bias is applied, a large electric field with a double peak structure is observed
- the profile slowly evolves to a single peak
  - collected current amplitude decreases
  - E_r = -12 kV/m inside limiter
  - strong E_r shear ($dv_{ExB}/dr \approx 3\times10^6\ s^{-1}$ at r-a=0 mm)
  - dv_{ExB}/dr exceeds 1/t (correlation time of fluctuations) about 20 times. Supresses turbulent fluctuations



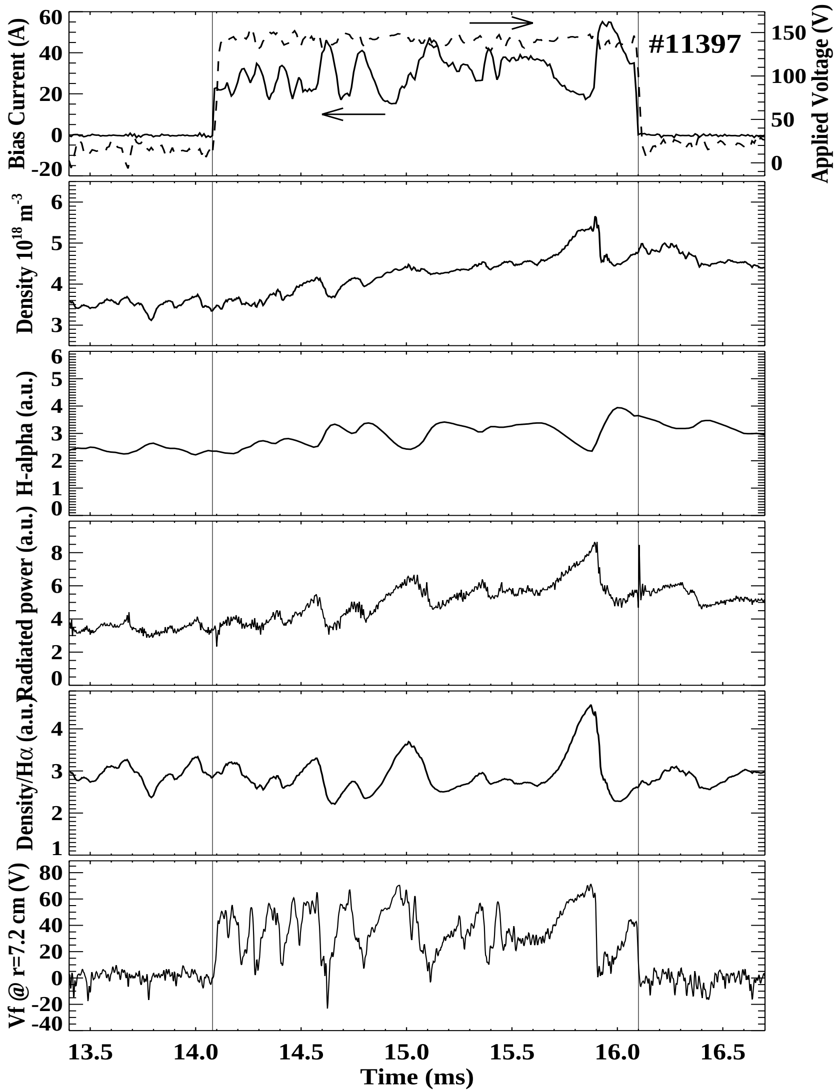
- edge density profile becomes stepper as the bias is applied
- during ICEs the edge density gradient increases even more with a clear density reduction observed across most of the scrape-off layer
- consistent with the observed reduction on the fluctuation induced particle flux and suggest that confinement enhancement originates at the edge plasma as a consequence of the formation of a particle transport barrier near the limiter
- during biasing $n_e\sigma_{eff}$ is observed to increase across the whole profile, being that increase larger for negative bias





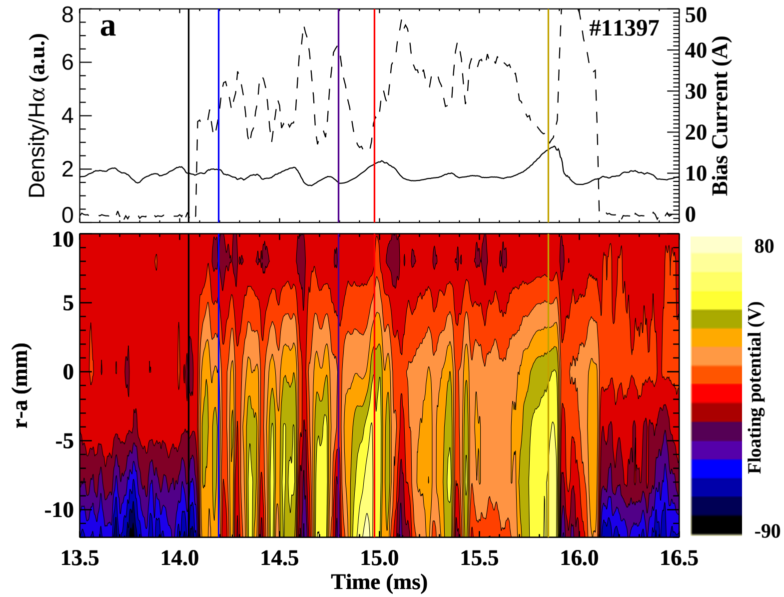
Positive electrode bias

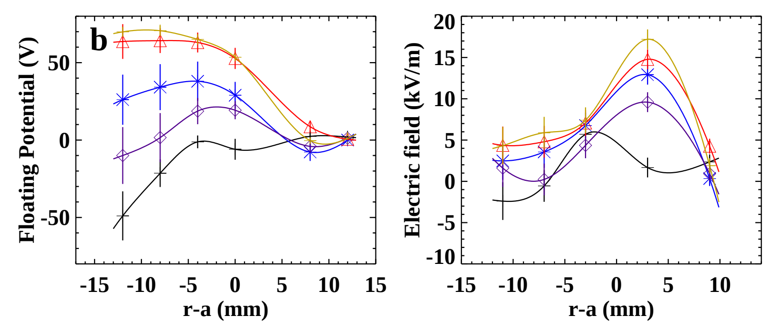
- For large positive bias (Vbias>50 V), the emissive current is zero. No significant difference between hot and cold electrode
- H_α increases as n_e increases, leading to modest increase in t_P
- Positive bias increases recycling
  - ICEs occur also (I_{bias} > 20 A)
  - E_r increases, collected current decreases
  - ICEs duration, frequency and amplitude less regular



Evolution of the radial plasma profiles for positive bias

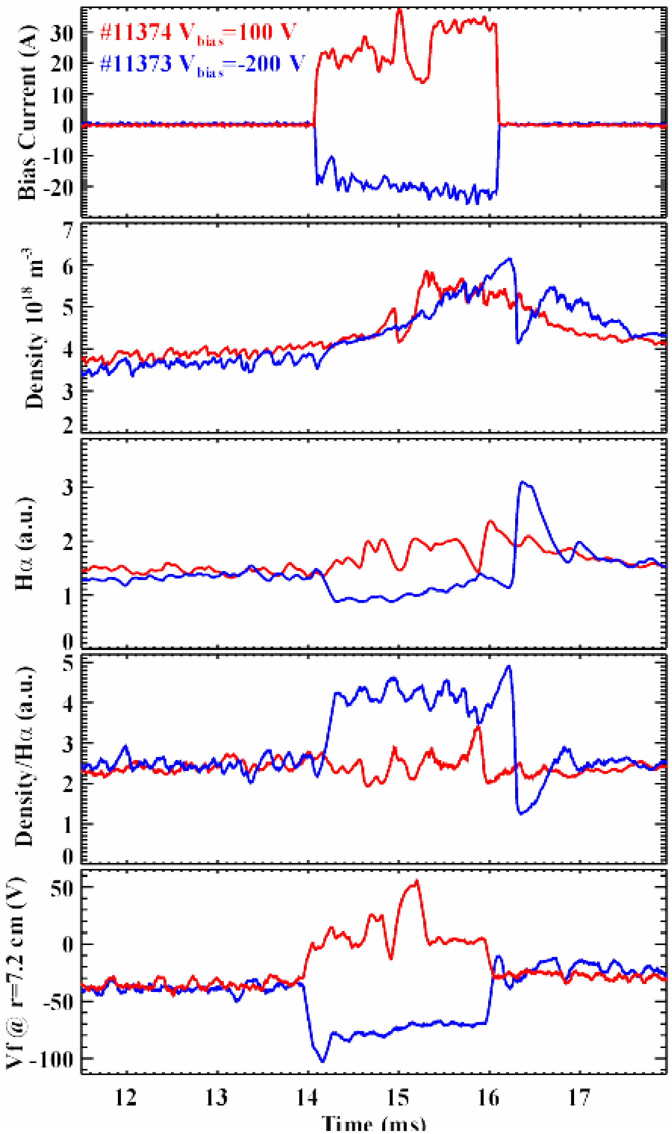
- E_r reaches a maximum when the current attains its minimum
- E_r is only significant (>5 kV/m) within a narrow region (<8 mm) around the limiter radius
- for negative bias the region of enhanced field starts just inside limiter radius and extends for more than 10 mm
- no double-peaked structures are observed in the radial electric field, suggesting that these structures are related with transitory localized space charge formation, caused by the emitted electrons





Negative/Positive Bias

- Both bias polaritys modify the floating potential
- Both bias polaritys increase the density
- Positive bias also increase H_α
- Gross confinement increases for negative bias



Conclusions

- The EE is an effective tool to lower the edge plasma potential compared to previously used limiter and standard electrode

- Improved particle confinement is clearly observed for negative bias associated with a large radial electric field. In some cases a double-peaked profile of the radial electric field is observed just after biasing, evolving afterwards to a single-peaked profile as confinement improves

- Above a certain threshold of the bias current stronger improved confinement events are observed, during short periods, for both bias polarities