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Experimental characterization of AC discharges transition in ISTTOK

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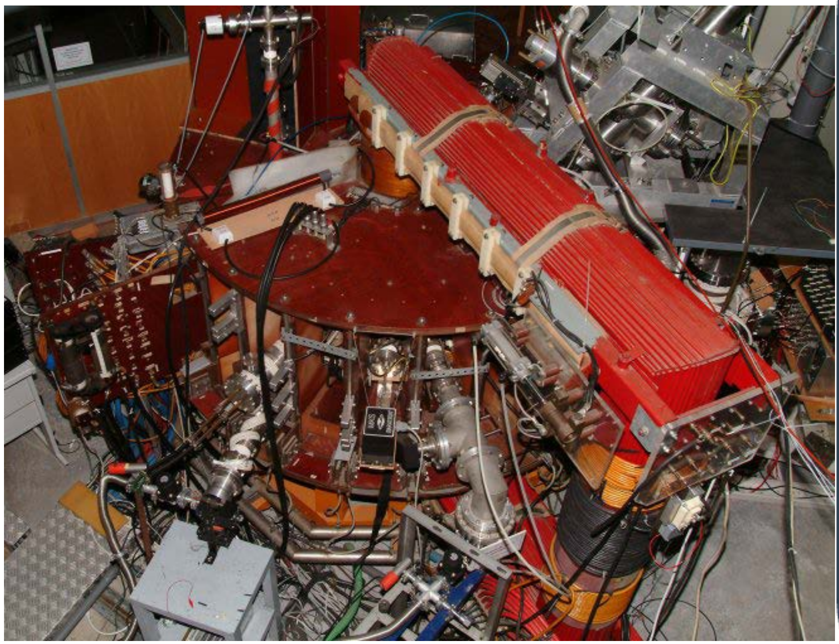
ISTTOK

Typical parameters



Major radius 0.46 m

Minor radius 0.085 m

Plasma current = 4- 8 kA

Toroidal field < 0. 45 – 0.6 T

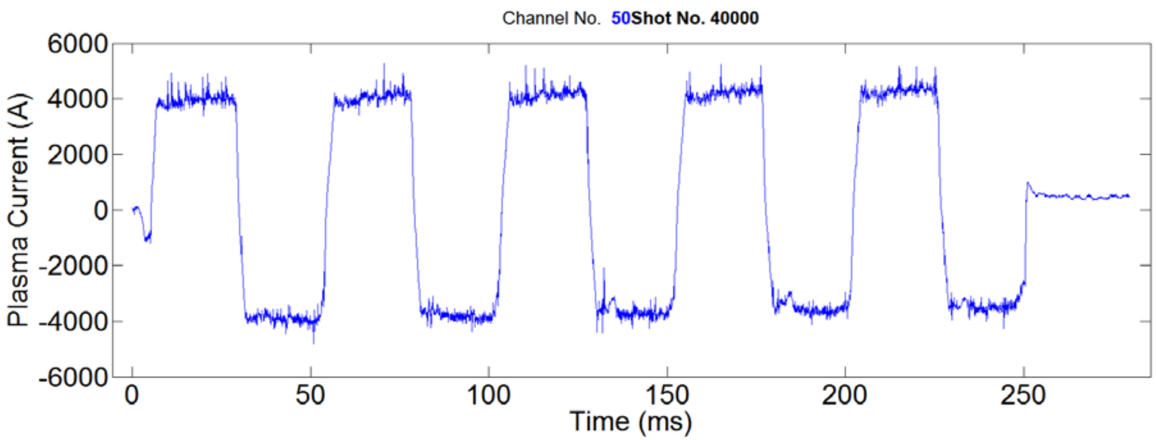
Discharge duration ~ 1s (AC), 35ms(DC)

Plasma density = 3-5x10^{18} m^{3}

Electron temperature (center) ~ 30 - 120 eV

Toroidal flux swing = 0.25 Vs

Energy confinement time ~ 0.3 - 0.4 ms



Goal

- ❑ Increase current of AC discharges
- ❑ Develop efficient plasma Control
- ❑ Increase time exposition and deposition power on test PFCs

Diagnostic techniques used in ISTTOK

(for the present experiments)

Magnetic and Electric Probes

Optical (photodiode)

Hard X-ray

Interferometer

Heavy Ion Beam Diagnostic (HIBD)

Actuators

Programmable V/H magnetic field coils (wave form)

Plasma V/H position real time FB control (electric probes)

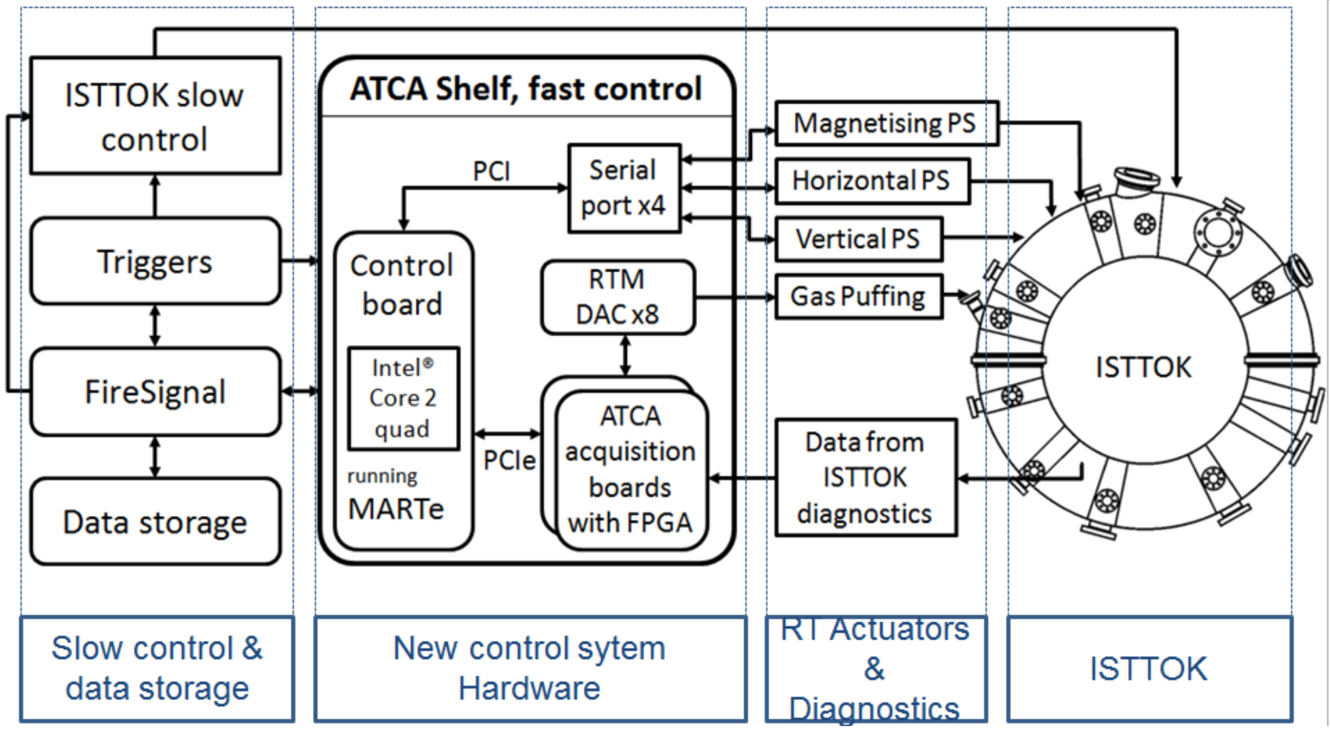
Plasma V position real time FB control (HIBD)

Real time FB control for plasma current (IGBT)

Real time Gas puff

Edge Biasing Electrode (+)

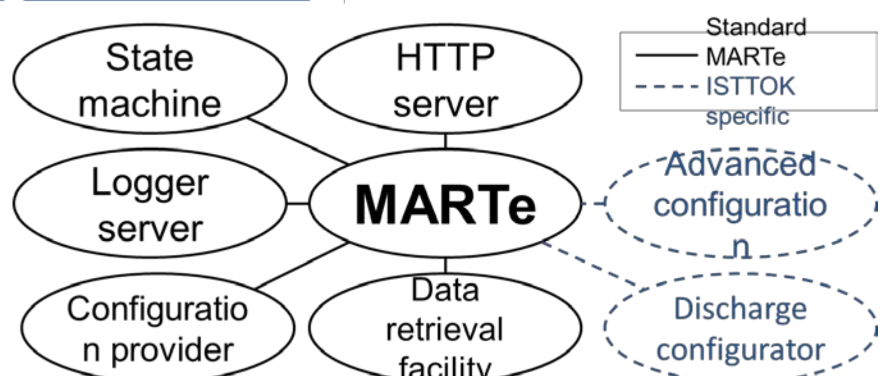
ISTTOK AC operation



Fast acquisition and control:

Telecommunications Computing Architecture (ATCA)

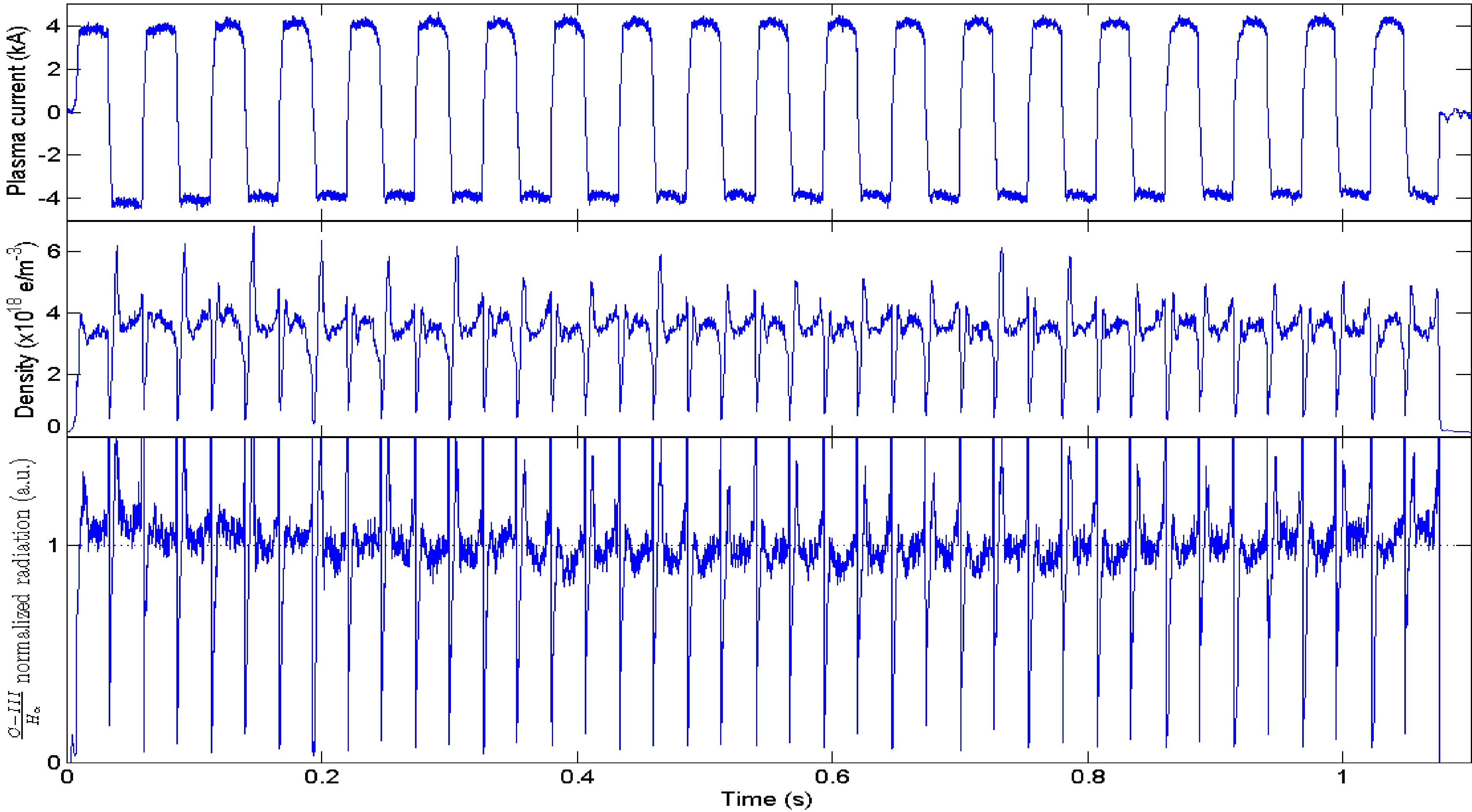
Multi-Platform Real-Time Framework (MARTe)



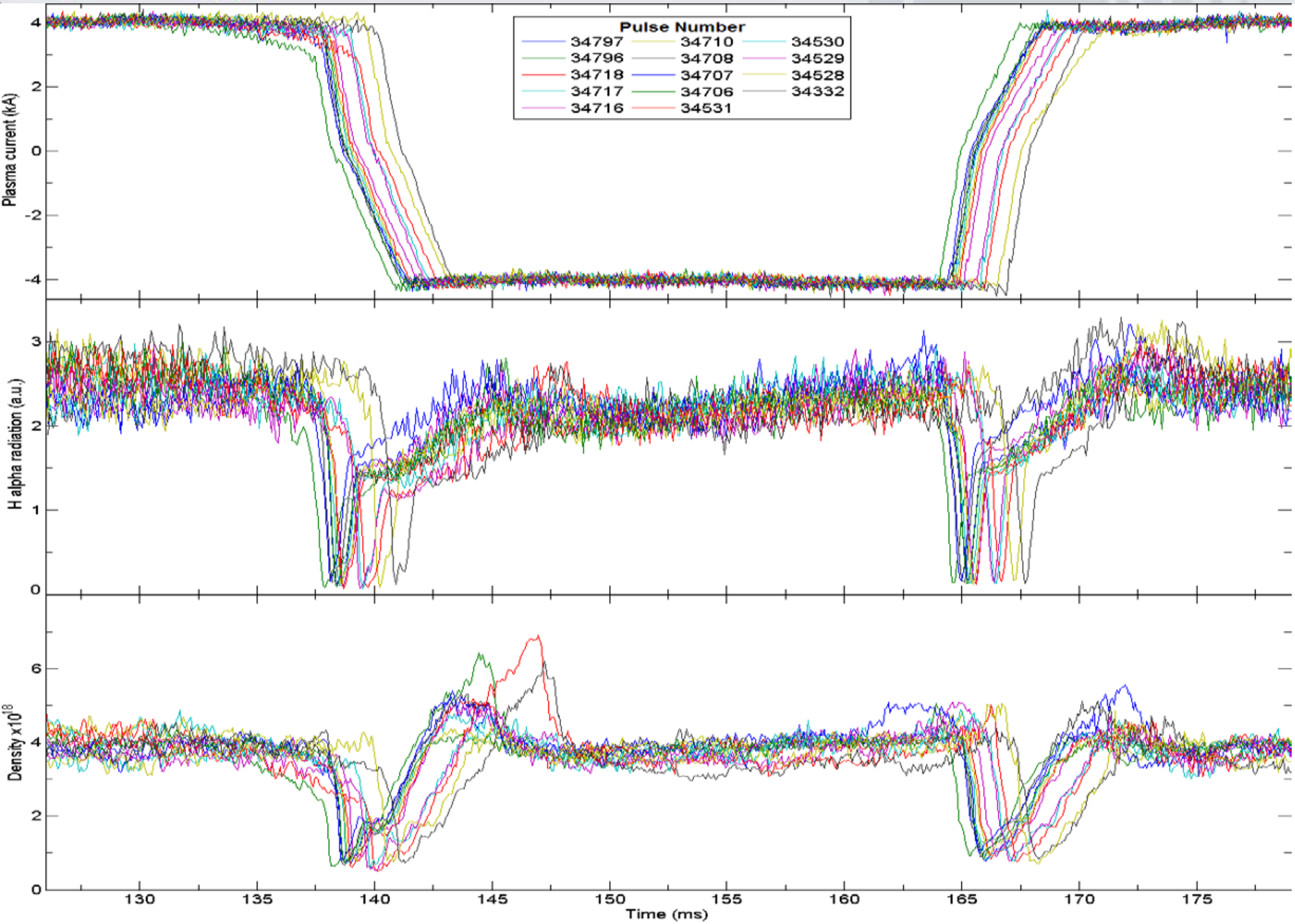
Outline

- **ISTTOK AC operation**
  - Plasma AC current and density evolution
- **The Heavy Ion Beam Diagnostic**
  - Principles
  - Pressure like profiles
  - Poloidal magnetic field measurements
- **Biasing electrode experiments (DC)**
  - Plasma confinement improvement experiments
- **AC operation experiments under electrode biasing**
  - Density increase (@ I_p=0)
  - Gas puff experiments
  - Runaway electrons
  - H/V external fields
- **Conclusions and future work**

ISTTOK AC operation: Ip = 4 kA



ISTTOK AC operation: Ip = 4 kA



ΔT_{AC} ~ 3 ms

(τ_c ~ 0.3 - 0.4 ms)

$\bar{n}\ (Ip = 0) \sim 1.10^{18}\ part./cm^3$

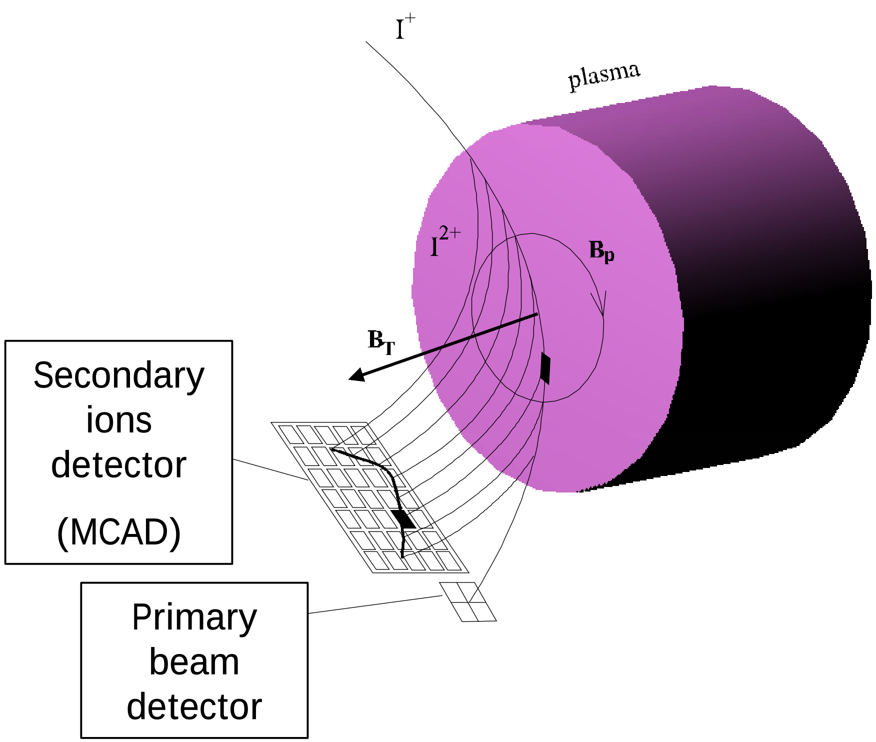
The Heavy Ion Beam Diagnostic (HIBD)

(development work in progress)

Can perform simultaneous <u>local</u> measurements of absolute profiles (up to several mm and few μs):

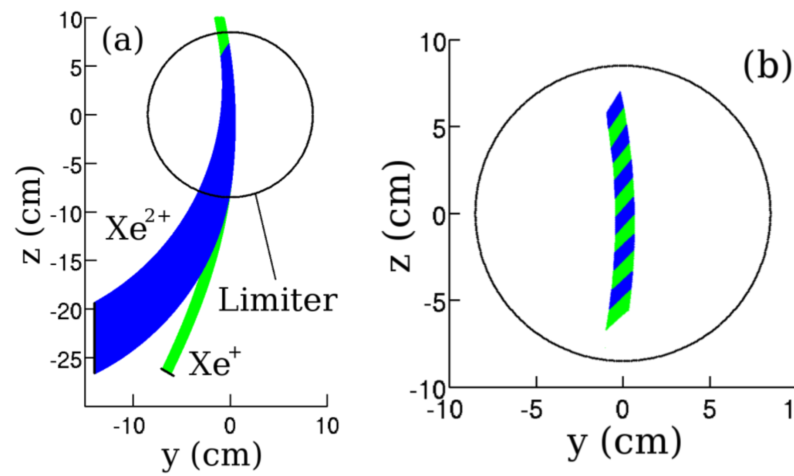
- Electron density
- Electron temperature
- Plasma poloidal field
- Plasma potential

Based: Multiple Cell Array Detector



Measurements for configuration 12x1 cells

- Pressure like: $I_{cell}\ \alpha\ n(r)\sigma_{eff.}\ [T_e(r)]$
- Integral poloidal field force: Δz_{pri}



Retrieval of plasma parameters

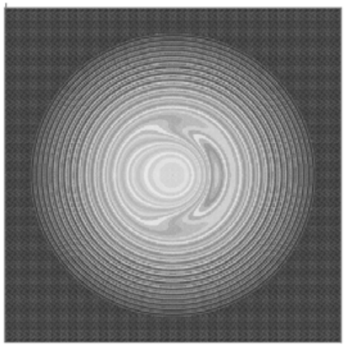
Pressure like profiles
retrieving the correct $n.\sigma$ values

(ne=6.5e18; Te=130 eV)

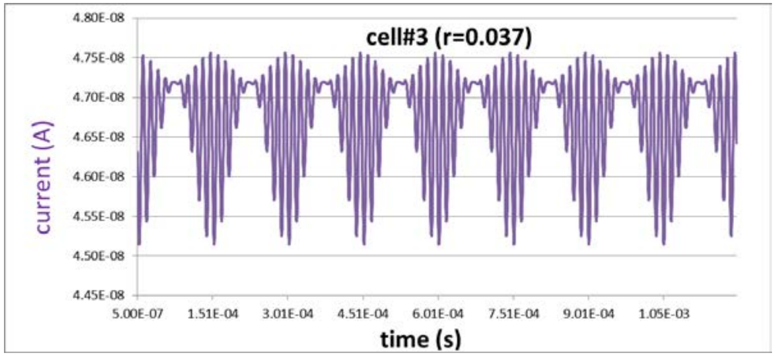
m=1; r=2.5 cm

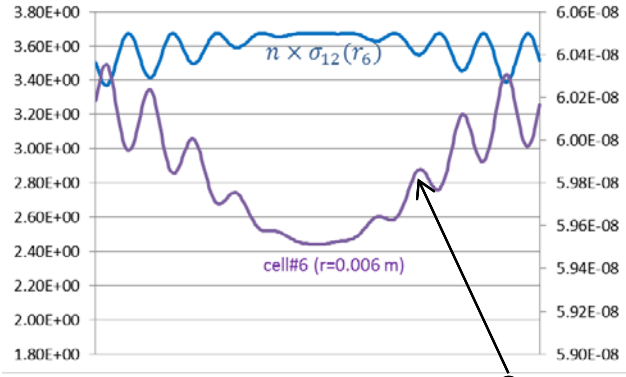
f=67 kHz

(mod. 6.7 kHz)

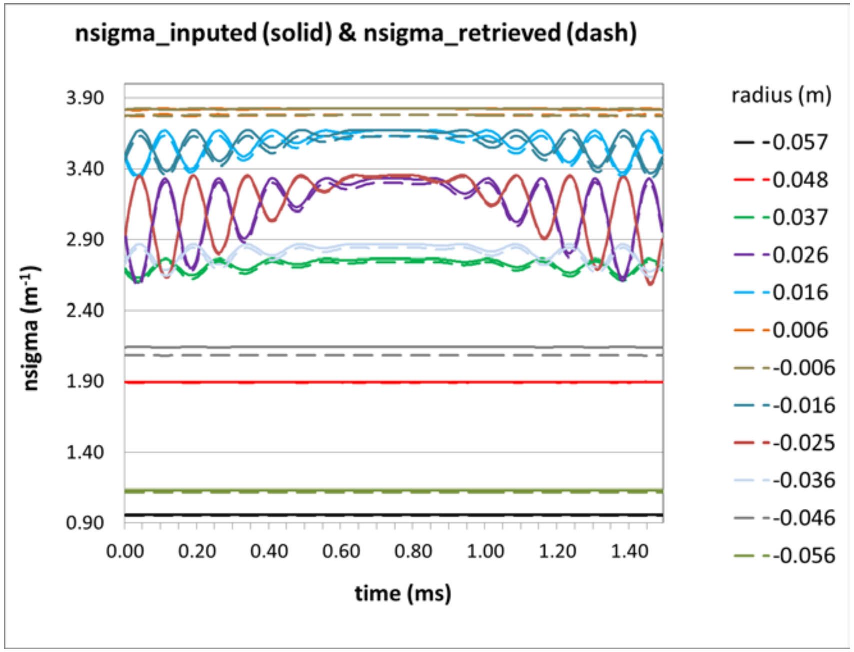


10 x 10 cm





Current in central cell



nsigma sample volume's profile

input -----

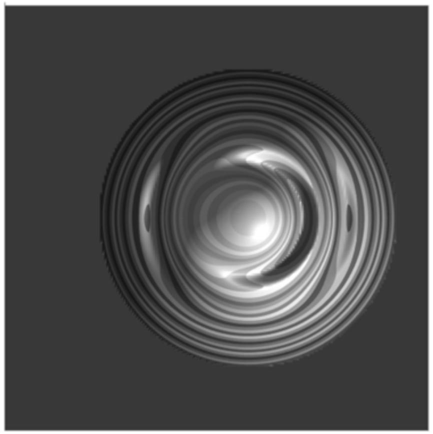
retrieved——

MHD fluctuations – retrieving the frequency composition

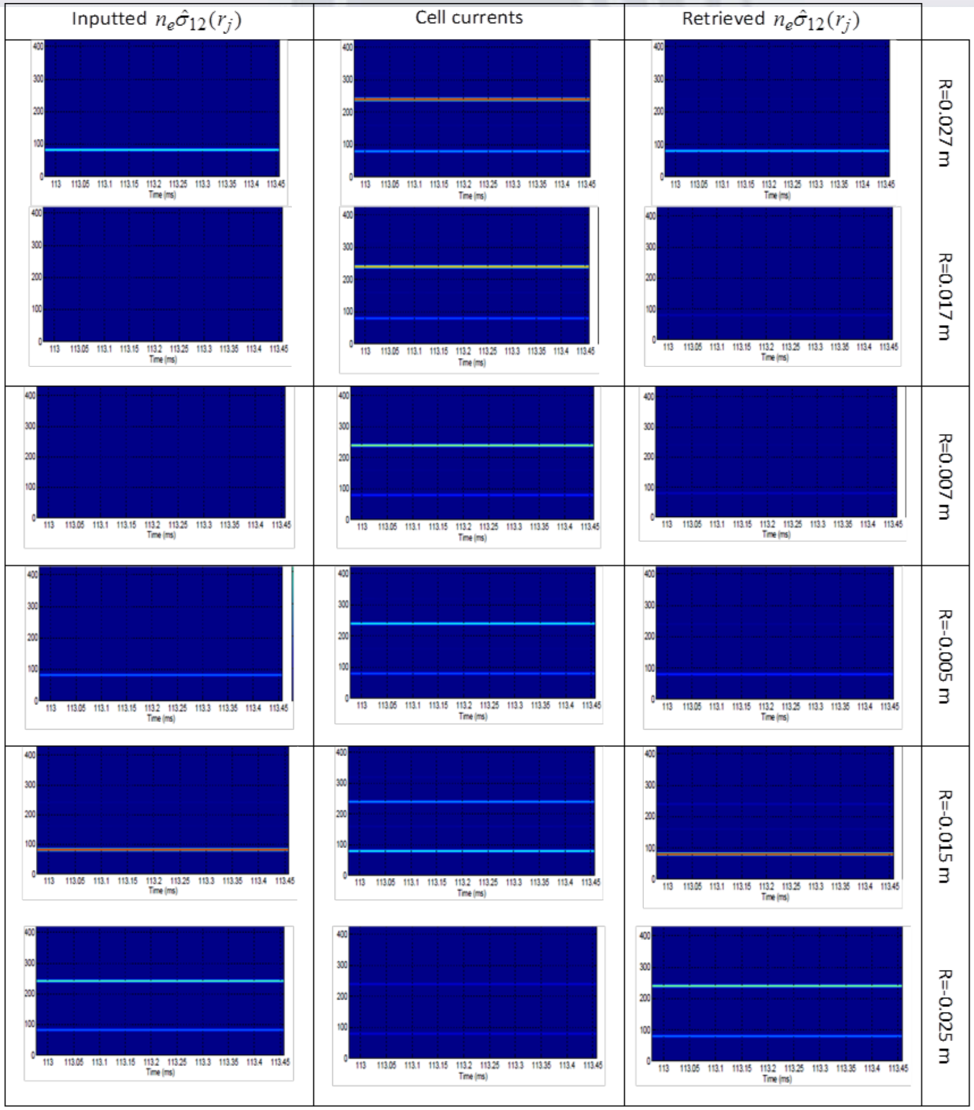
m=1 (r=0.025 m; 80 kHz) ;

m=2 (r=0.045 m; 120 kHz)

(ne=6.5e19; Te=1keV)

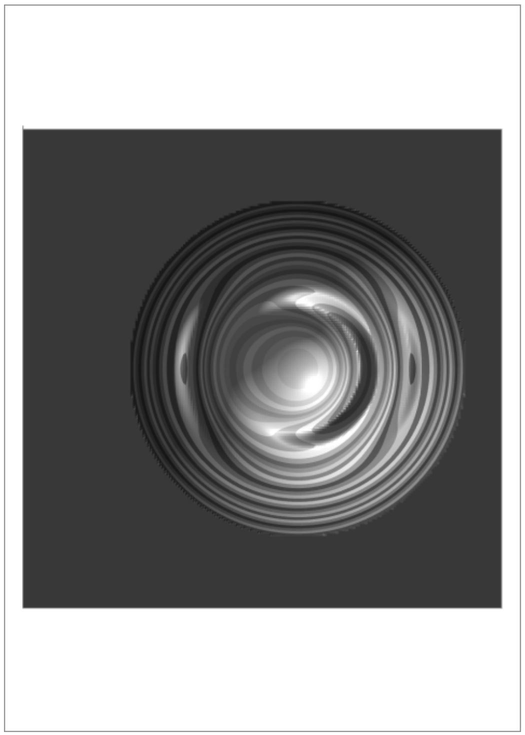


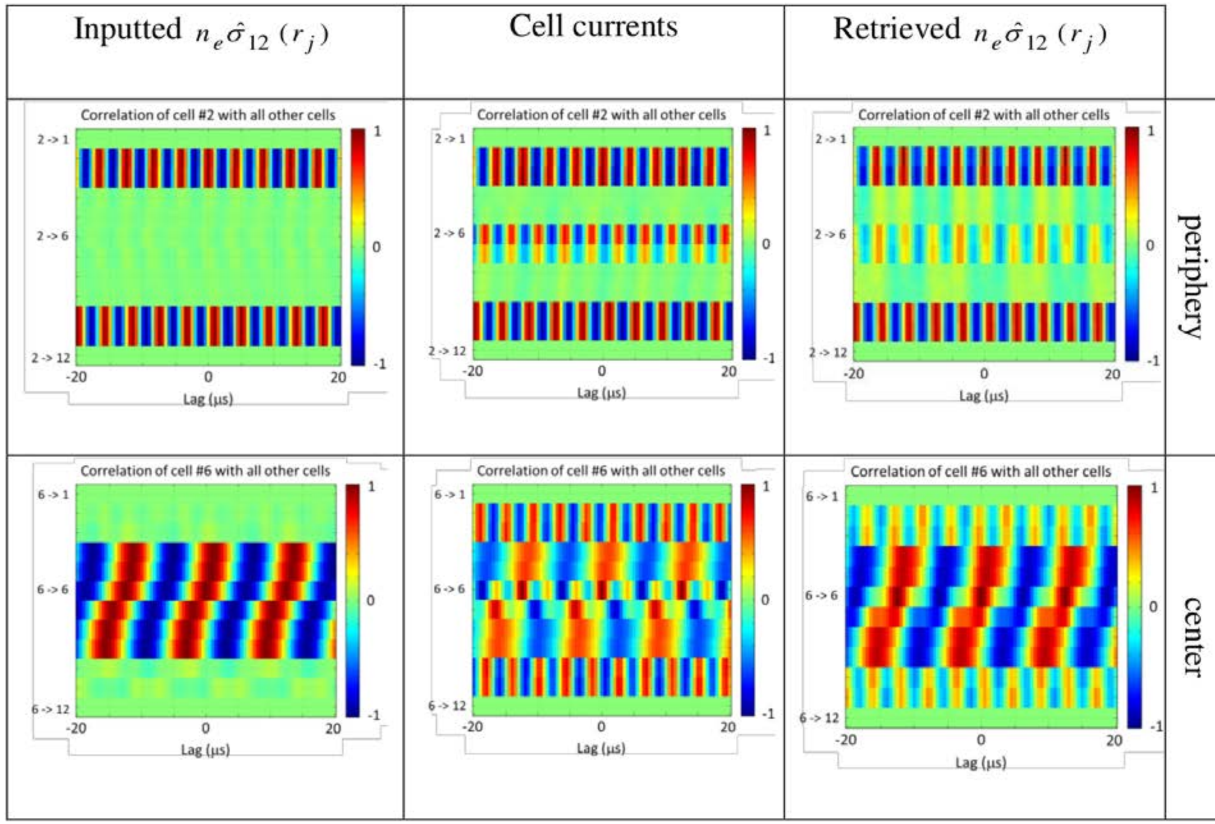
10 x 10 cm



m=1 (r=0.025 m; 80 kHz) ;

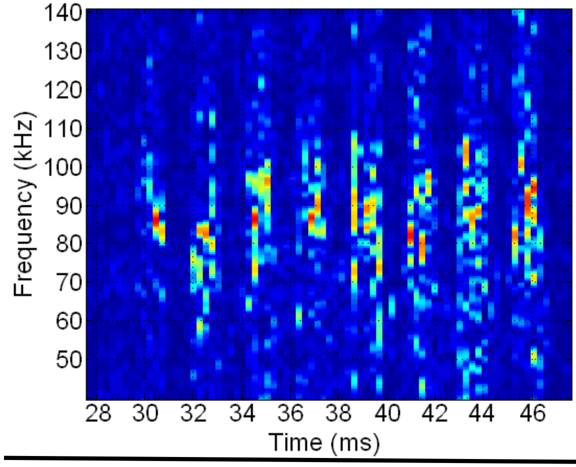
m=2 (r=0.045 m; 120 kHz)

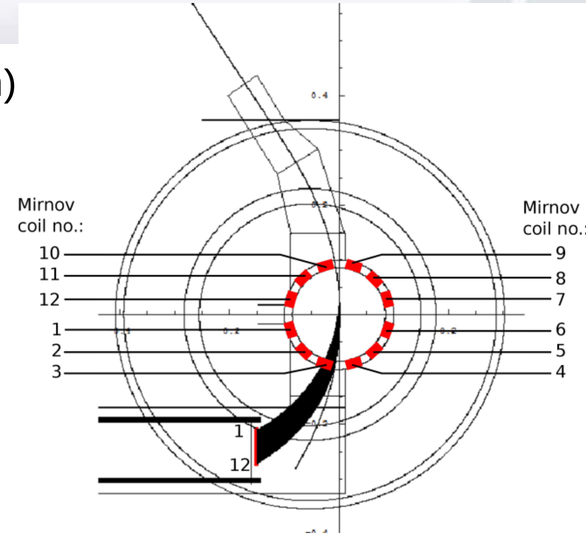


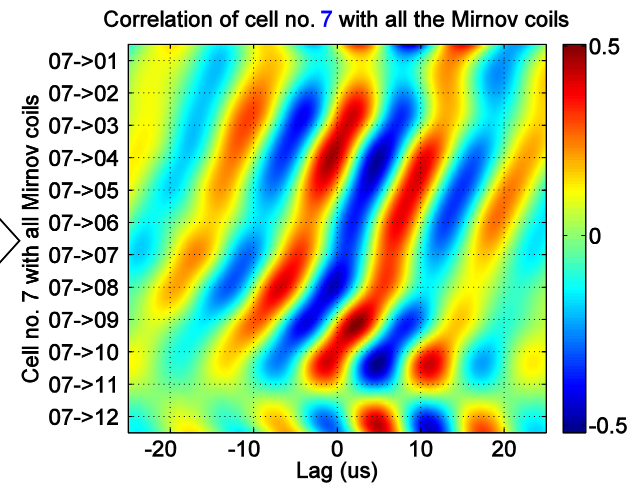


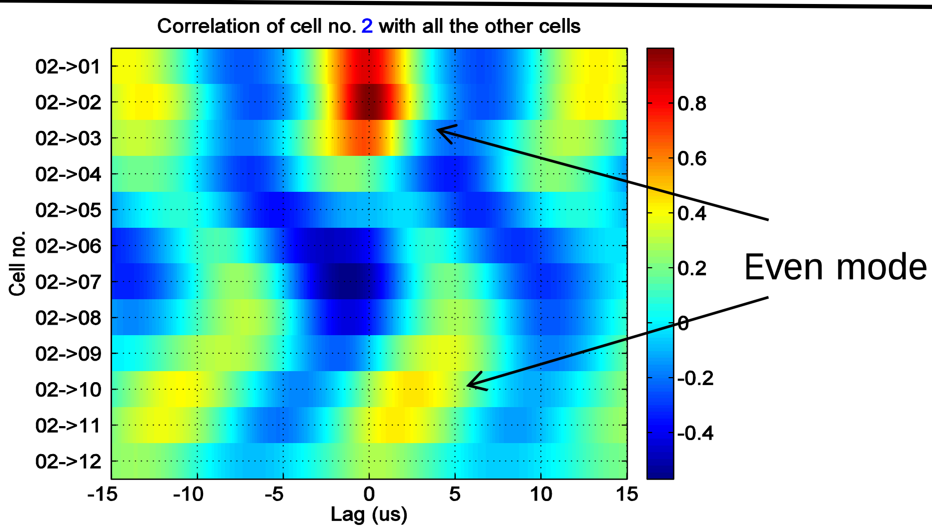
Experimental measurements MHD activity

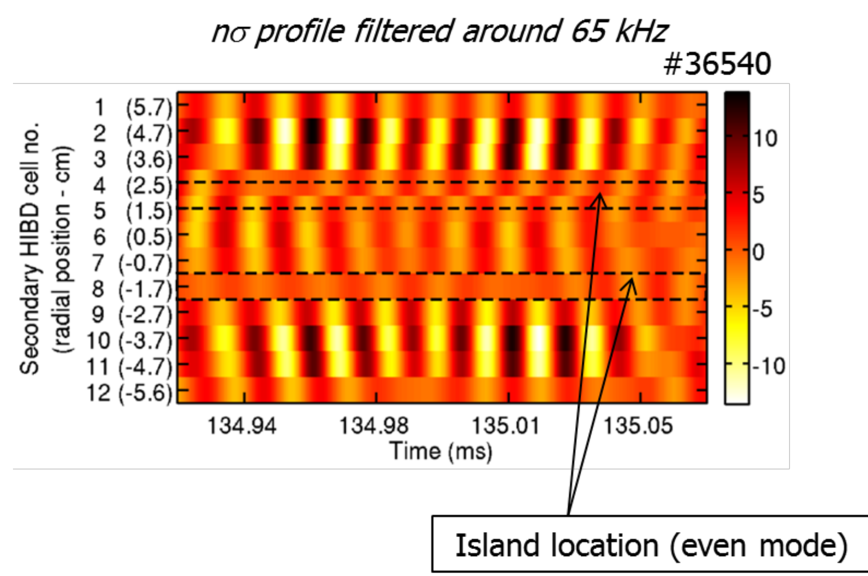
HIBD L=#7 spectra (pulsed beam)







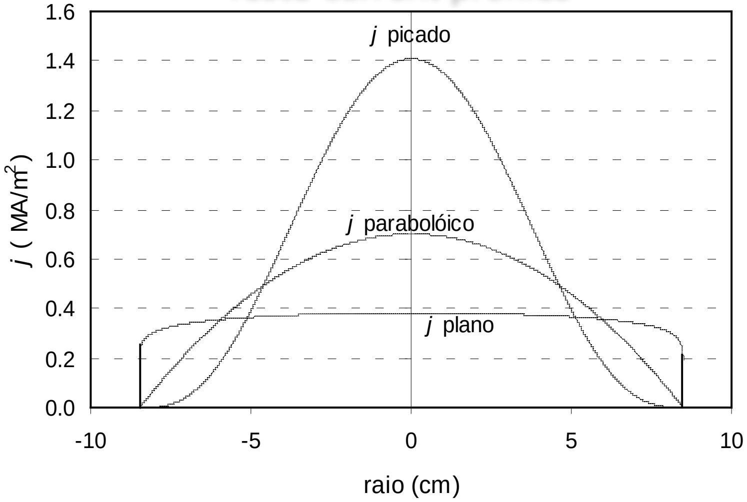




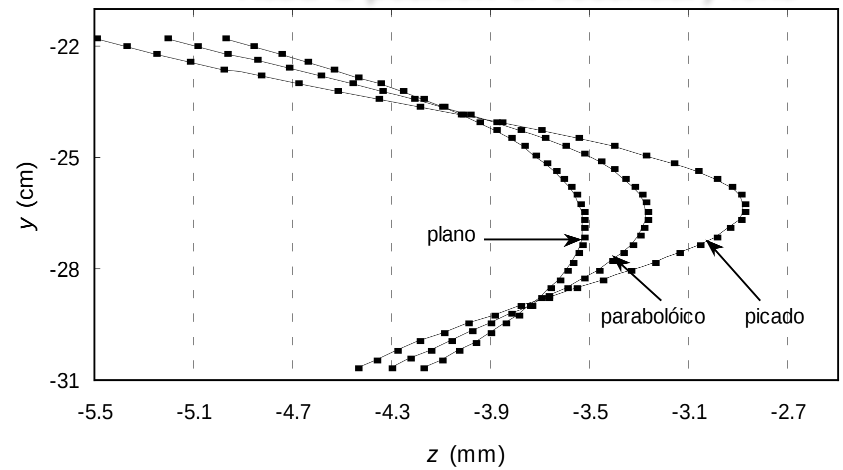
Bp

Plasma poloidal field determination

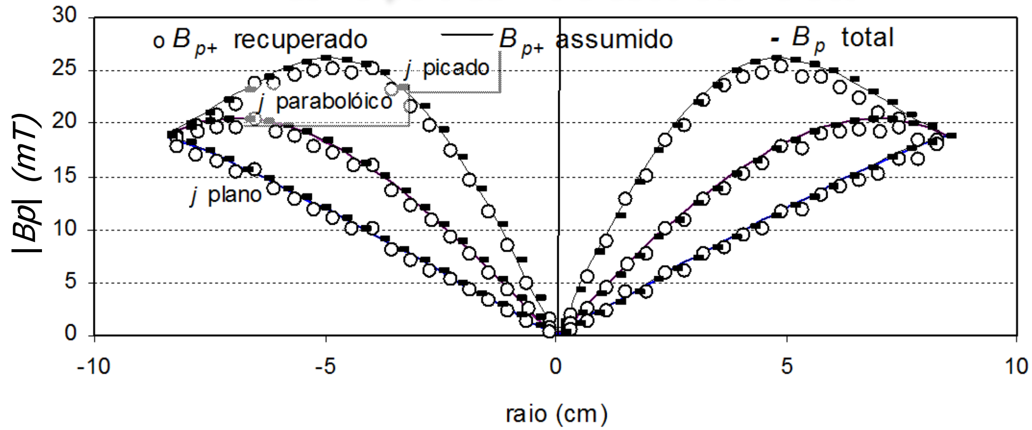
Teste current profiles



HIBD z-position of secondary ions



Plasma poloidal field absolute values



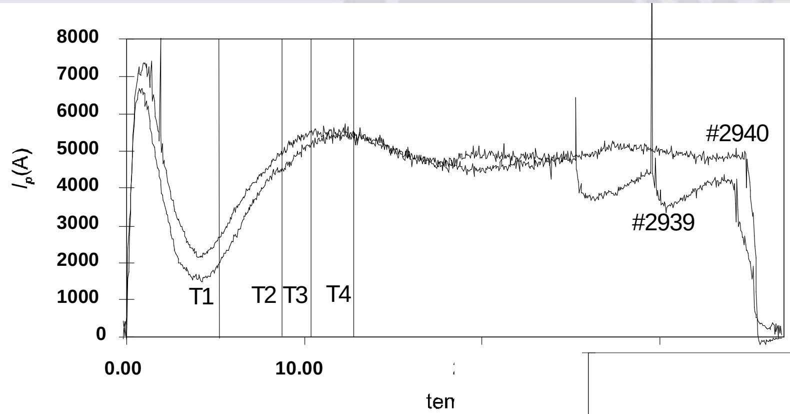
Input (test) ——

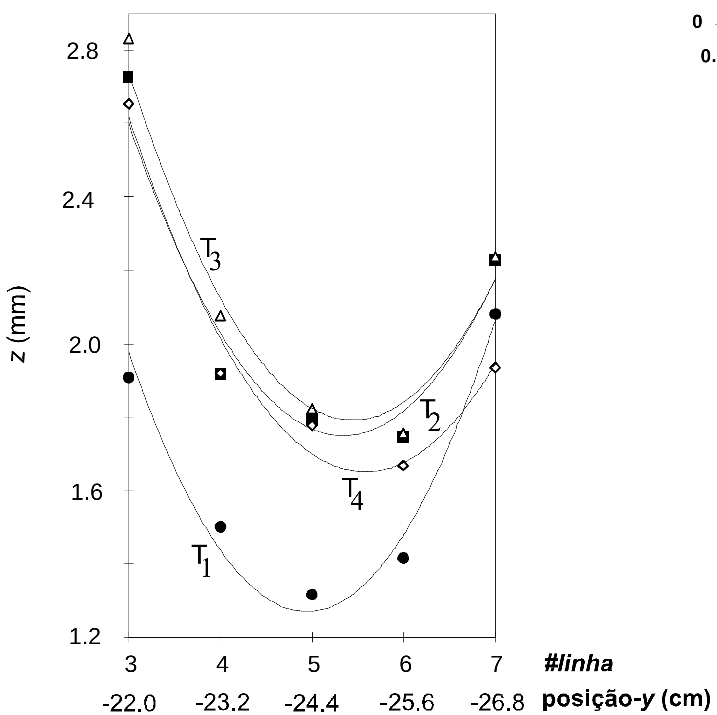
retrieved ○

Plasma poloidal field mesurements

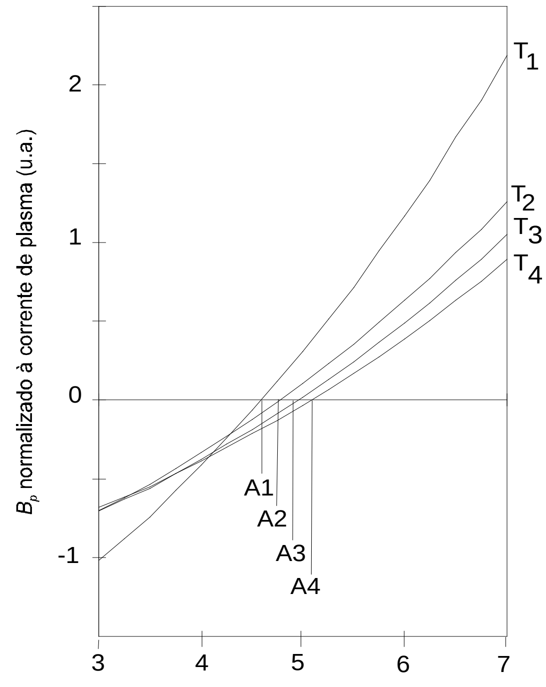
Two similar discharges were used

(due to limited number of ADCs)





Profile flattening (T1→T4)

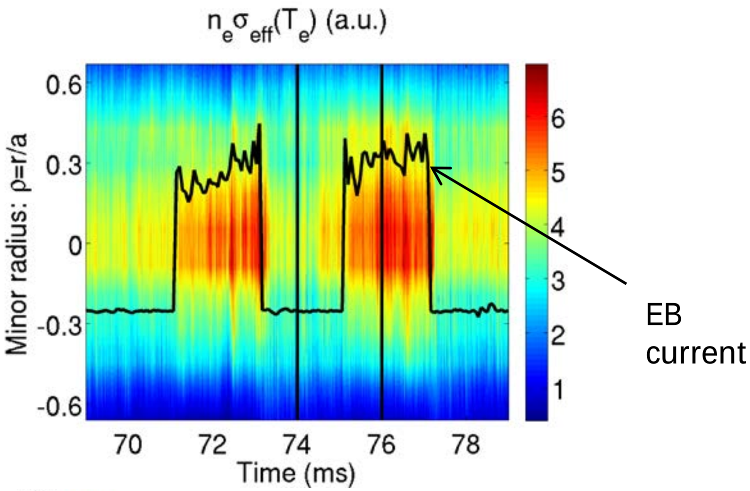


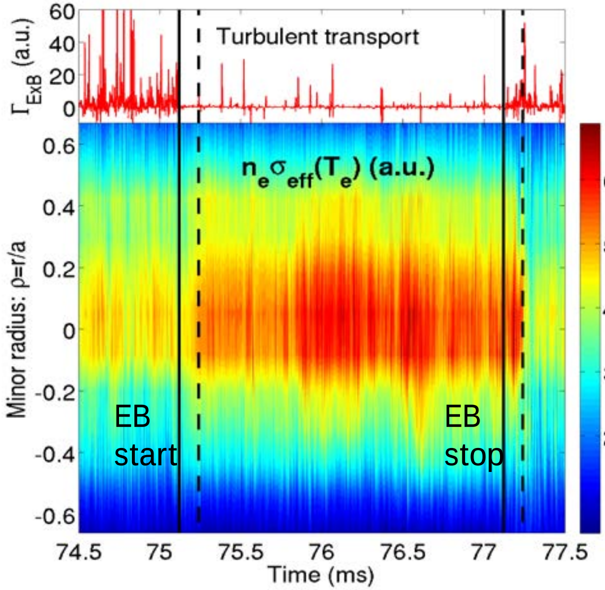
Magnetic axis displacement

Edge electrode biasing experiments:

DC discharges

Electrode biasing experiments

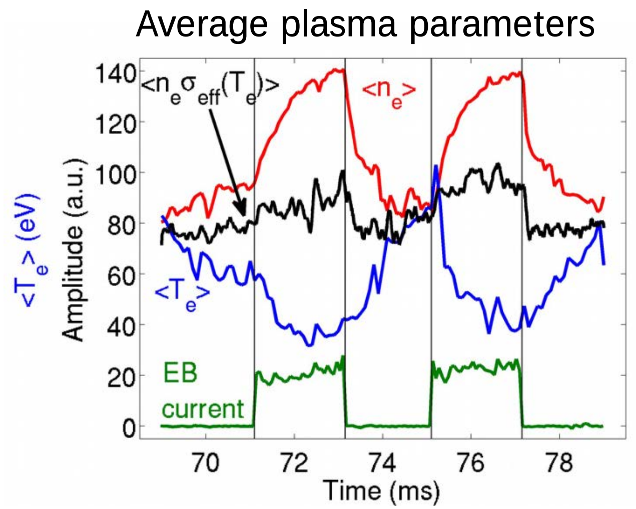


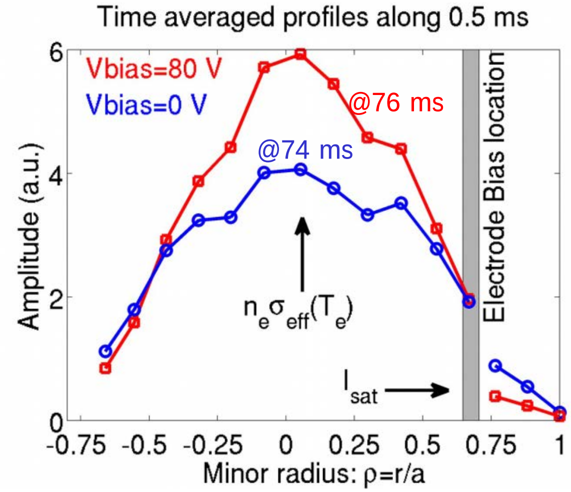


Turbulent transport is modified in a fast time scale (~10us)

The $n_e\sigma_{eff}(T_e)$ builds up in a slower time scale (~150us)

$n_e\sigma_{eff}(T_e)$ reaches its maximum almost 1 ms after the biasing





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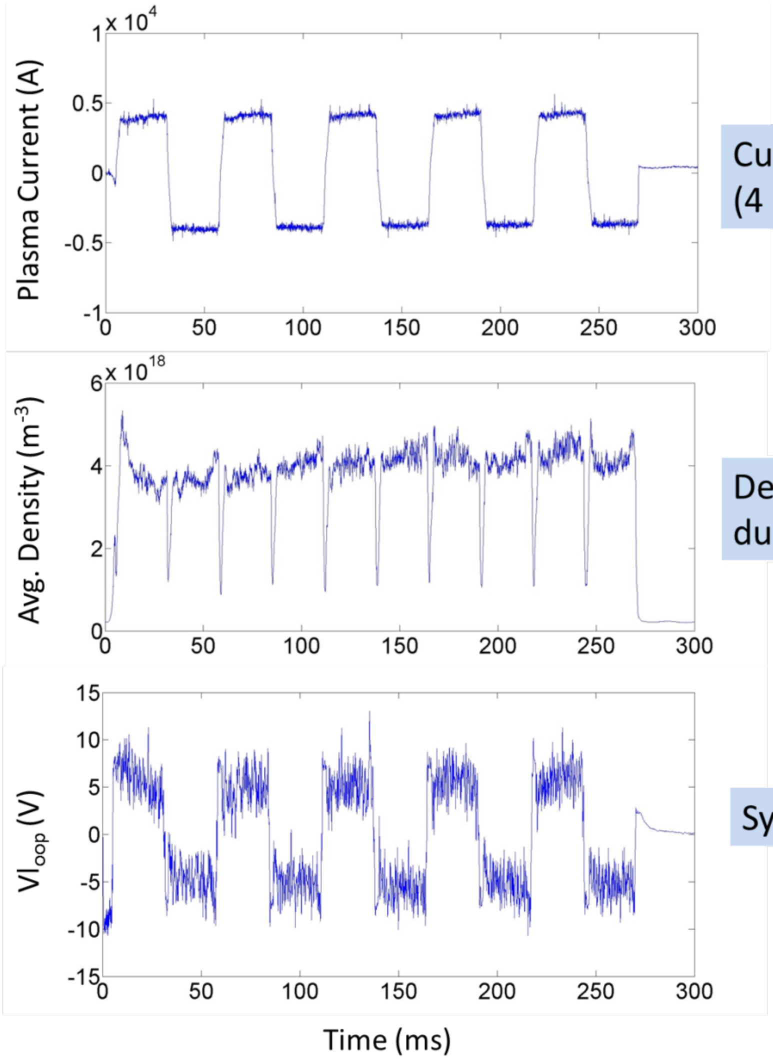
AC discharges: biasing electrode experiments

Typical parameters of AC discharge: EB = 0V

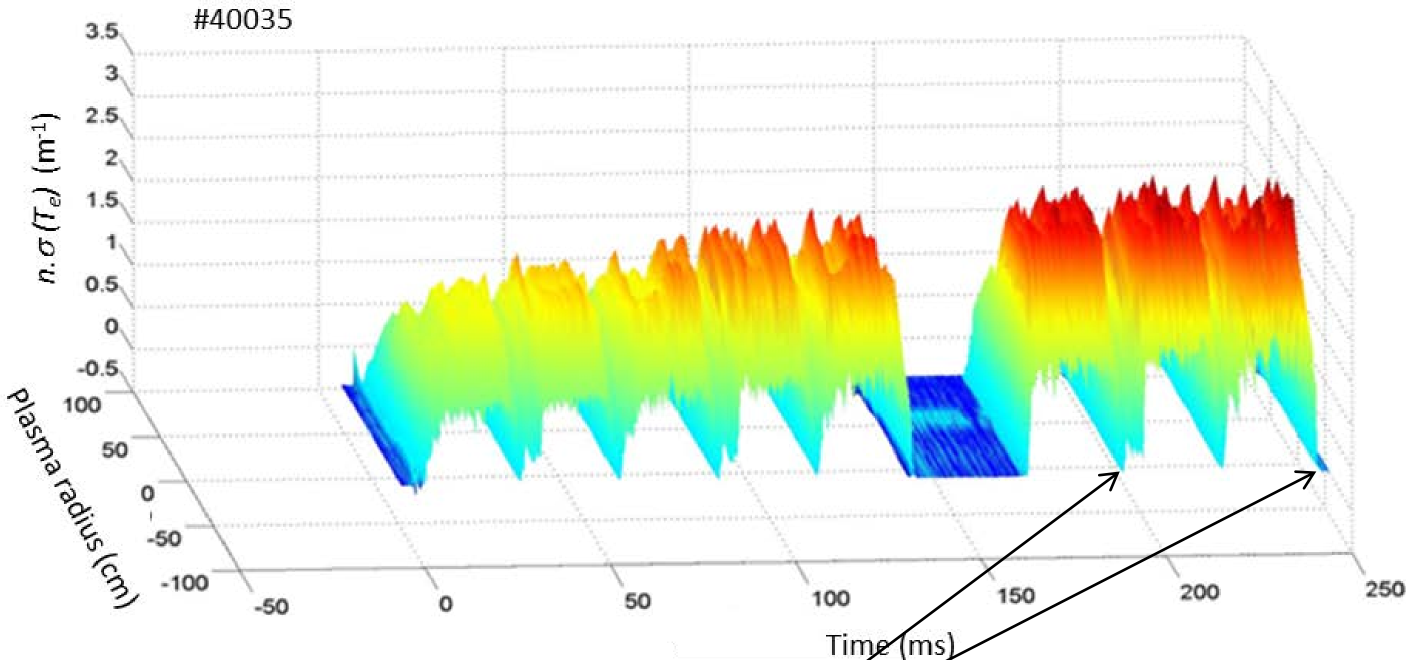


Current feed back control (4 kA)

Density does not vanish during AC transition

Symmetric V_{loop} for AC (+/-) cycles

‘pressure’ profile during failed transition: EB=0 V

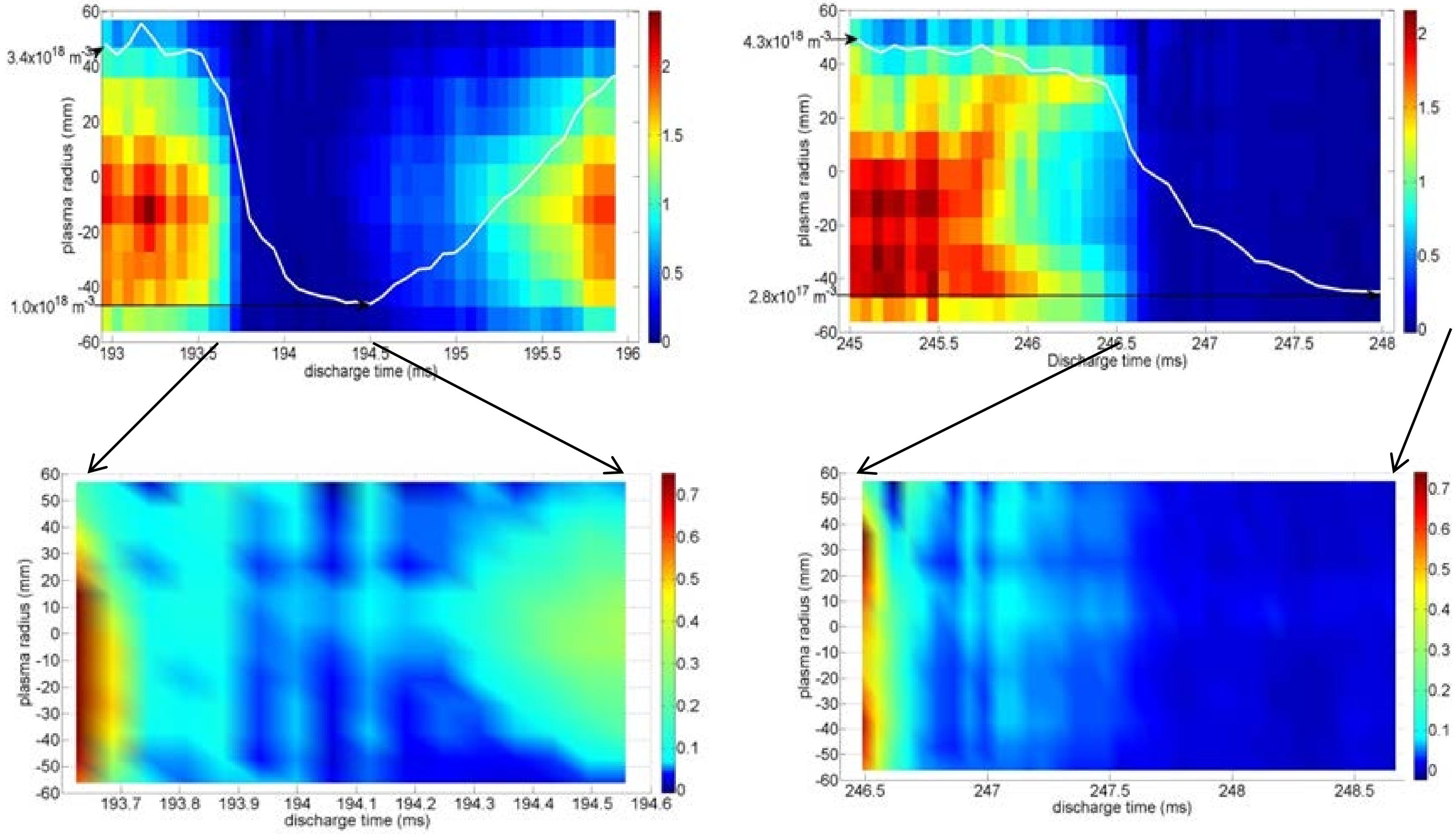


Check the profiles in detail

Nsigma @ transition: EB=0 V

White line – interferometer
Background - HIBD

Quescient plasma phase (0.7 ms) lasts longer than confinement time (<0.4 ms)

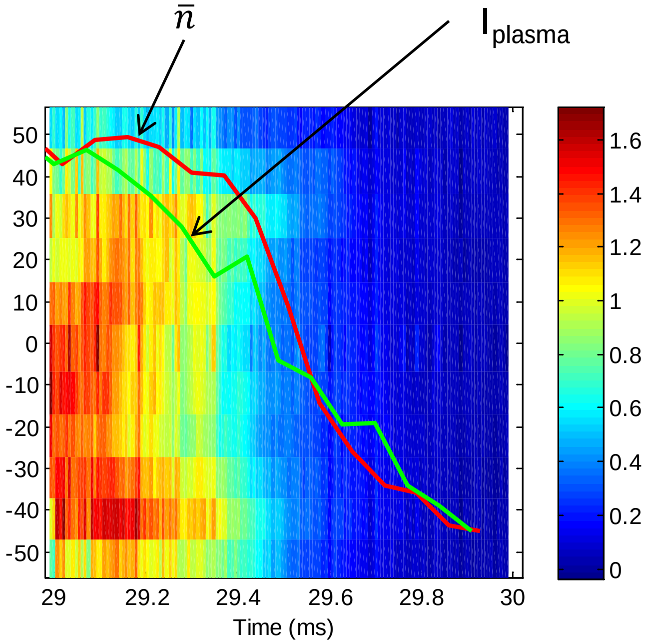


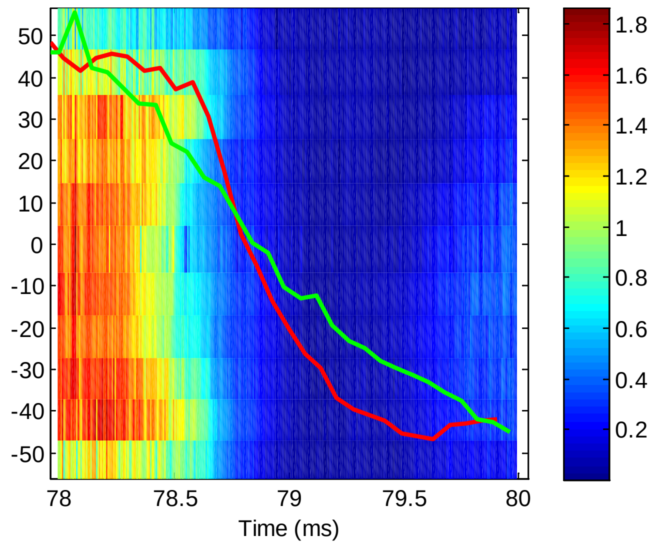
nsigma peaked profiles

nsigma hollow profiles:
Loss of temperature

Nsigma @ transition: EB=0 V

nsigma hollow profiles #39993

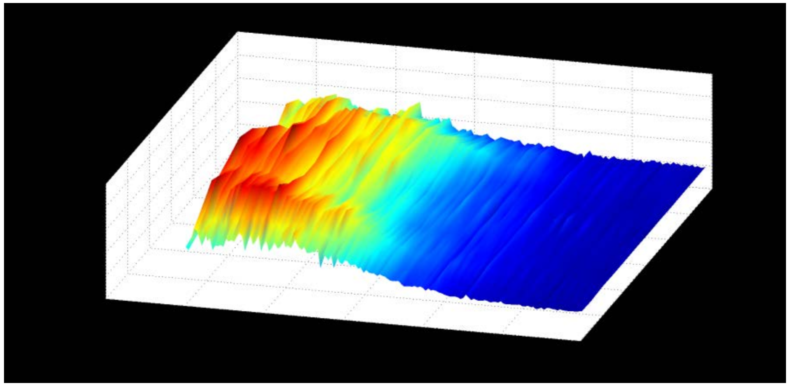


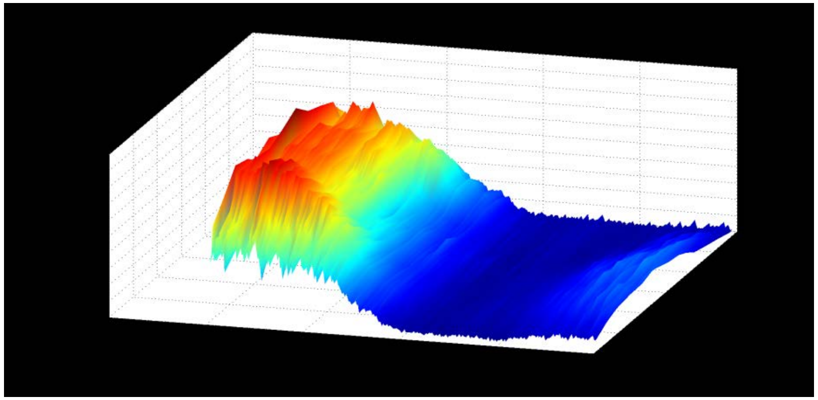


Density remains at top level up to 0.3 ms after current starts to decay

The plasma temperature drops within that period

Plasma pressure forms a hollow profile within that period



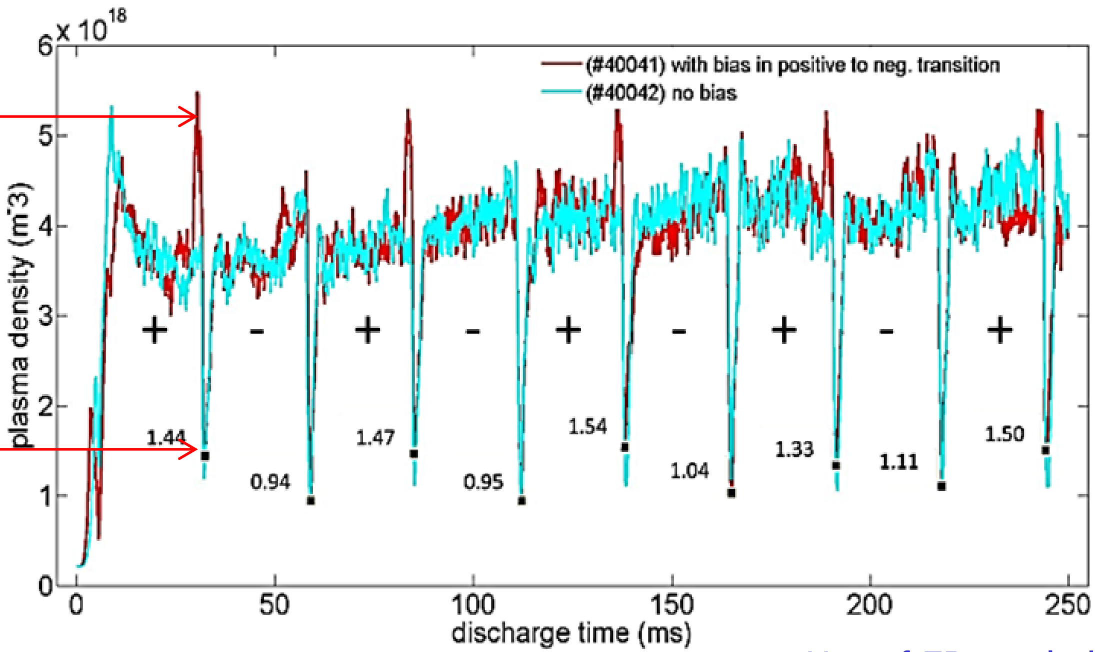


Density @ transition: EB=0 / 120V

Positive bias at 120V during 2 ms in each positive current semi-cycle (applied 2ms before transition)

Density increases:

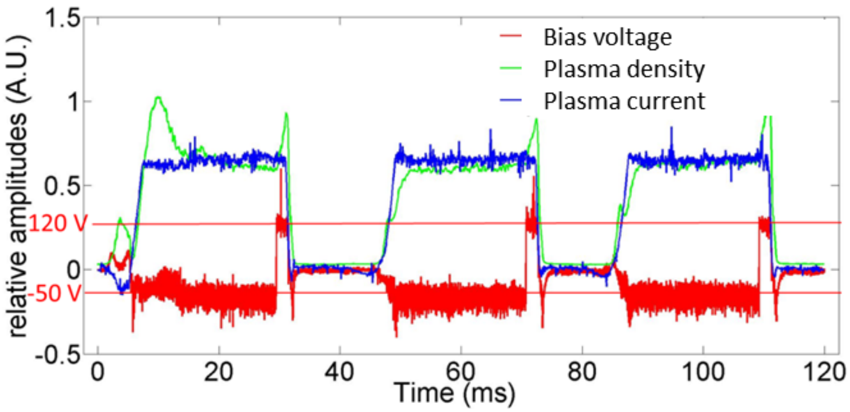
- before transition
- @ I_p=0



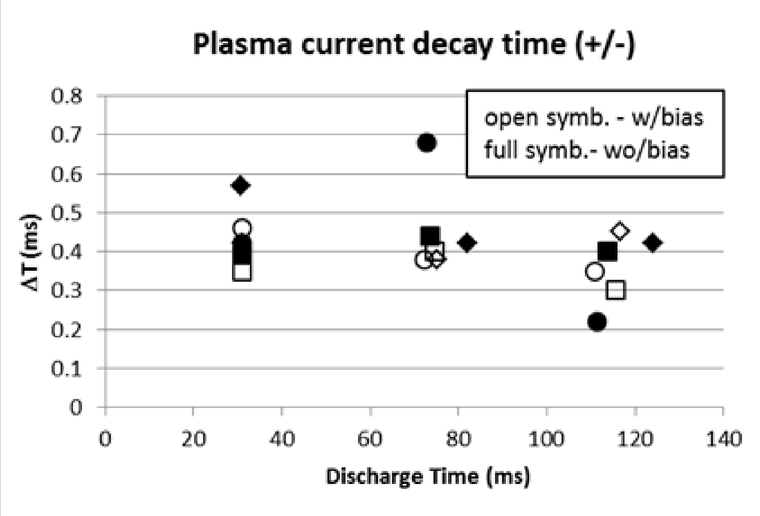
Use of EB can help to increase the plasma density during quiescent plasma phase → facilitates AC transition?

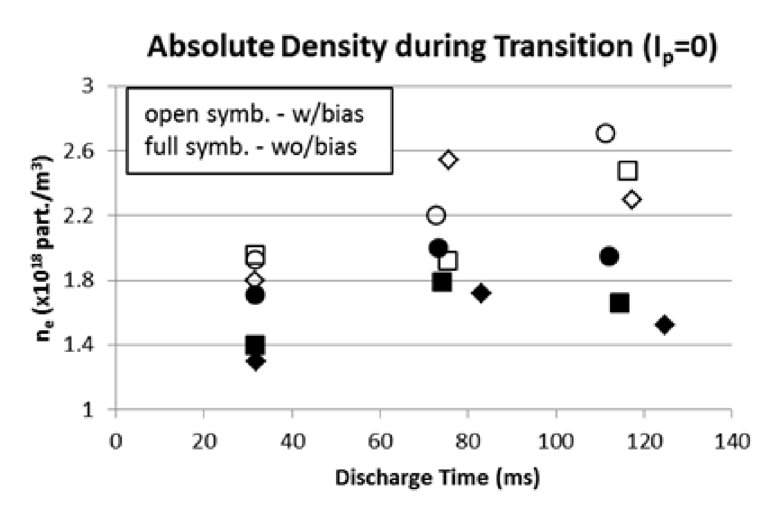
Ip = 4.5 kA; EB = 120 V; r = 6.5 cm

Collection of experiments during failed negative transitions



- Plasma confinement time is not affected by biasing
- Bias induces a density increase at Ip=0
- No improvement on the success rate of negative semi-cycle





The influence of other parameters

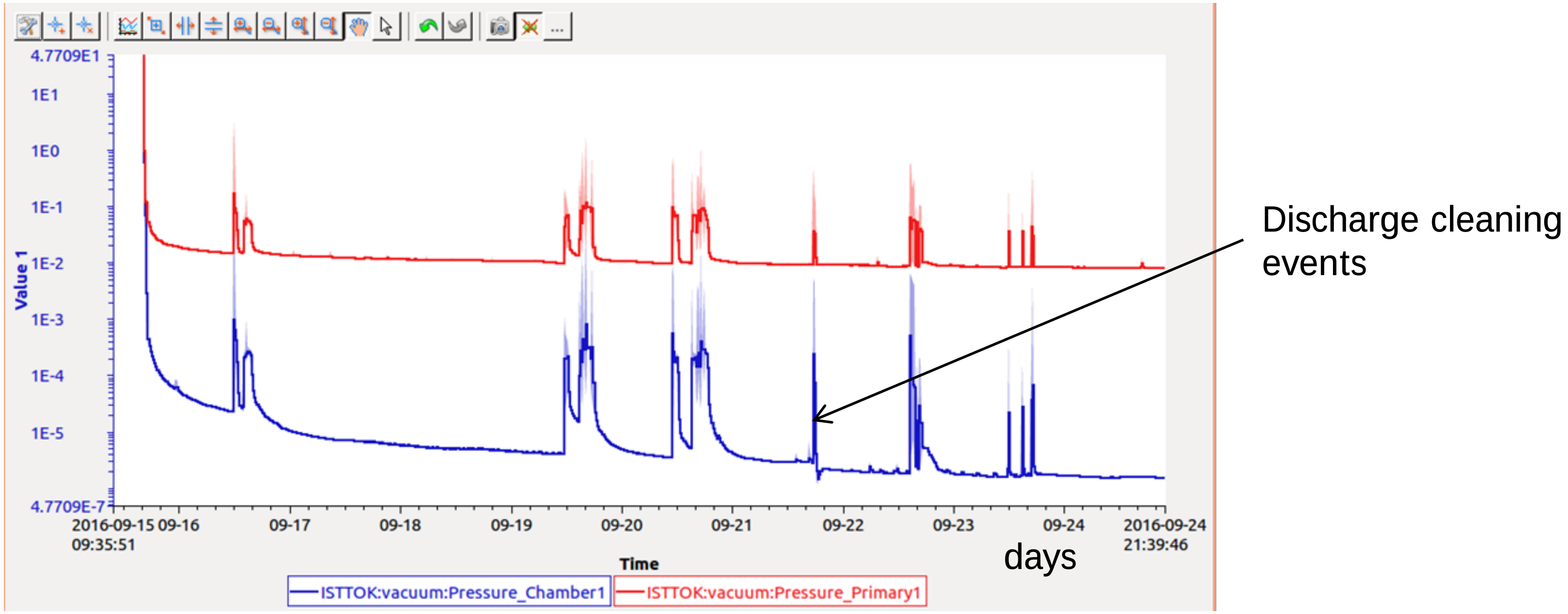
Several causes can be proposed for the failing of semi-cycles:

- Impurity contribution and neutral gas pressure
- Formation of fast electrons (drift)
- Existence of runaway electrons
- Offset of the plasma column (vertical and horizontal fields)

Investigation on the possible influence of these parameters for partially successful discharges at 4 kA under electrode biasing of 120 V

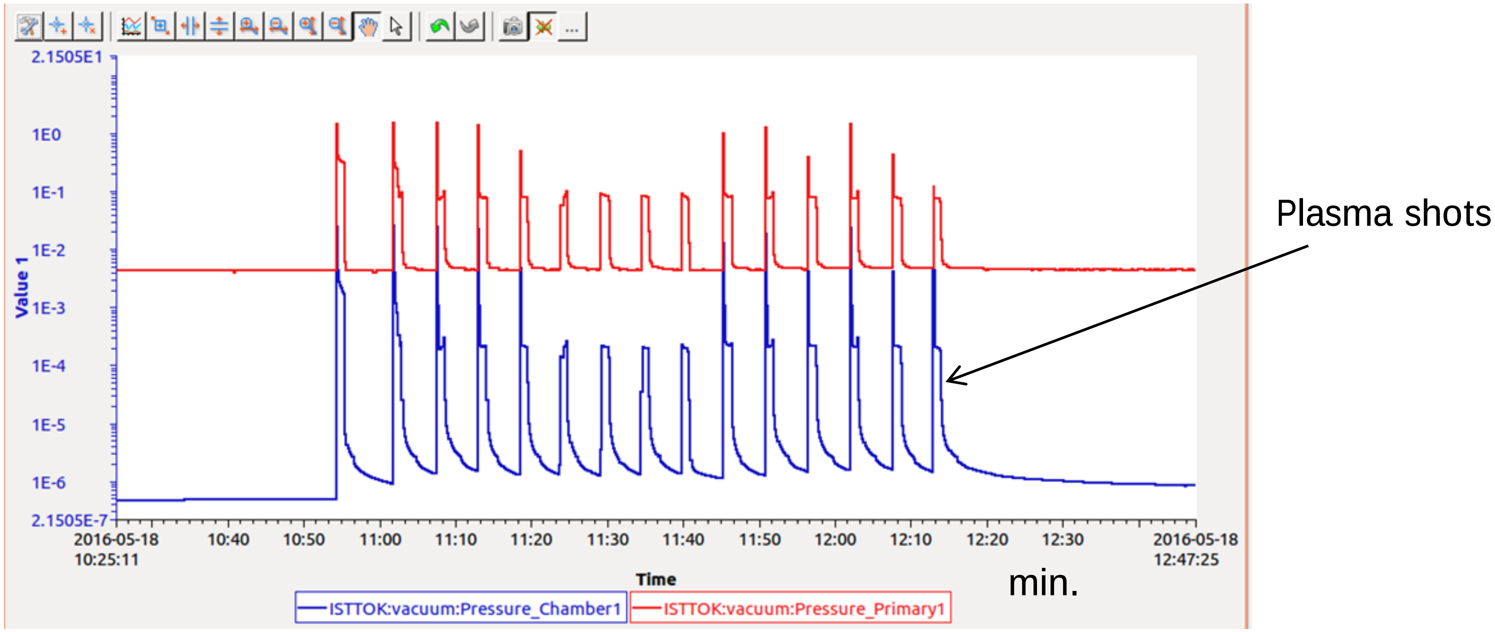
Impurity contribution and neutral gas Pressure (puff)

Evolution of chamber background pressure after shutdown



Requires several days of discharge cleaning to bring background pressure to operating values

Evolution of chamber background pressure during normal operation



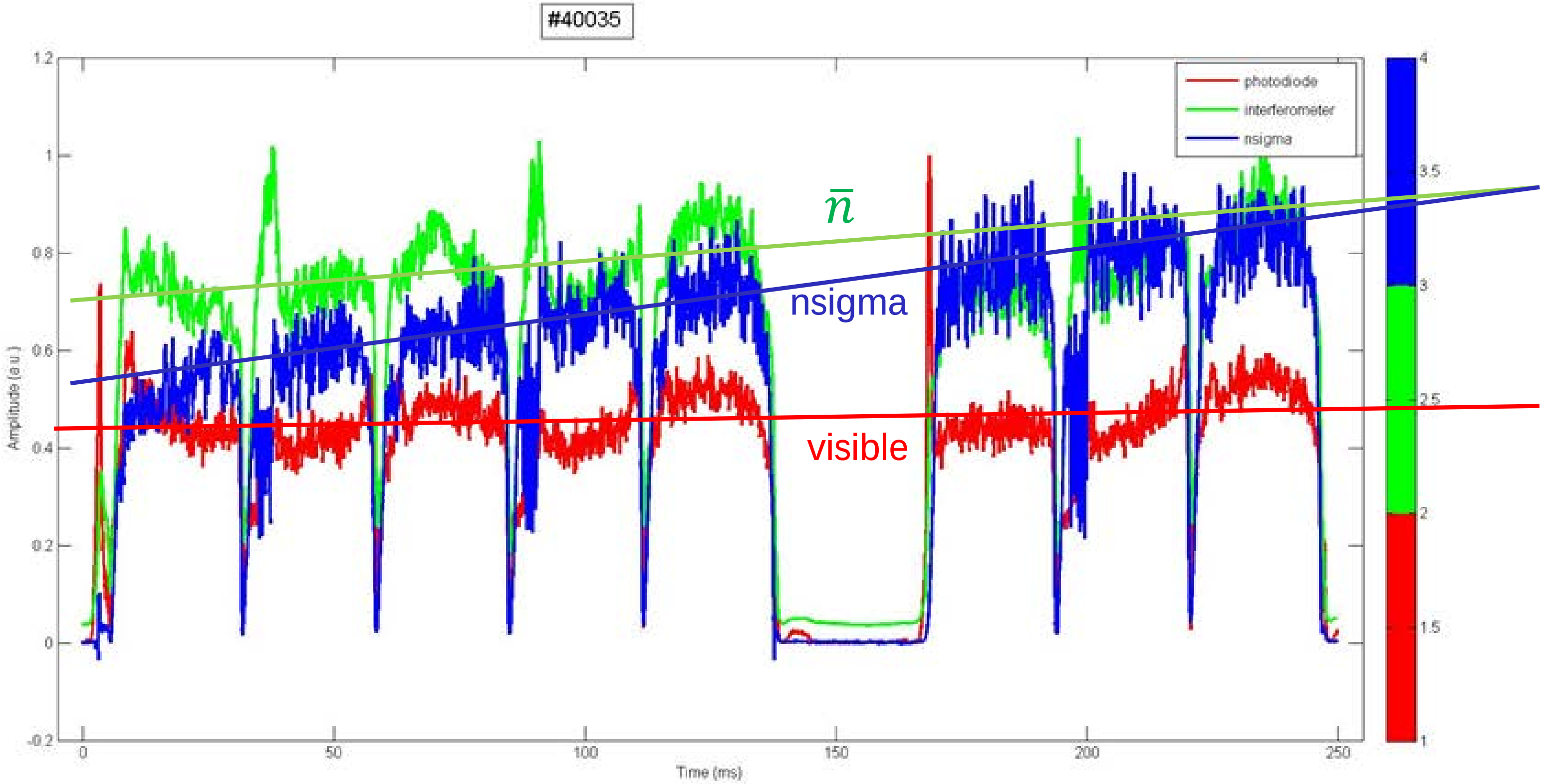
The background pressure always recovers to the same value between shots

Good conditioned chamber!

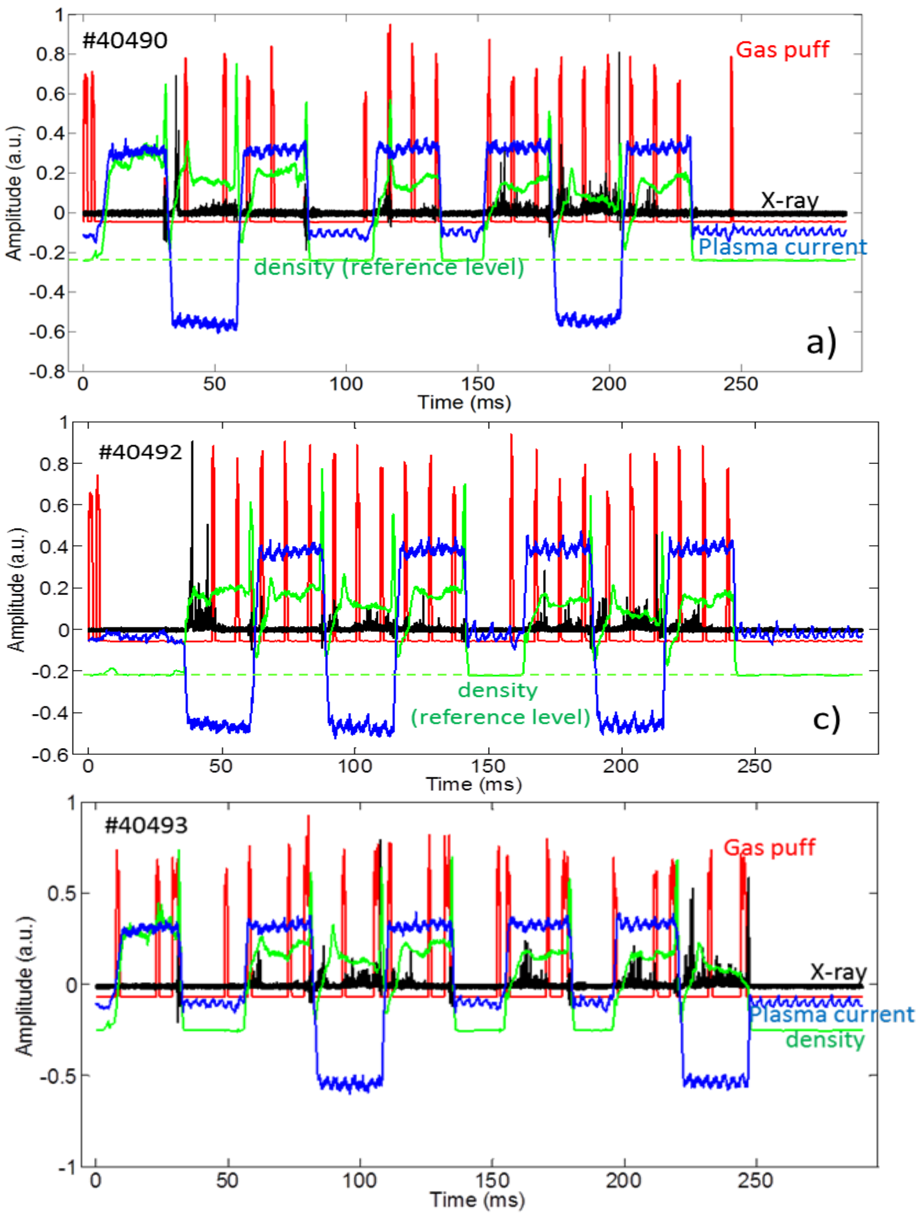
Impurity contribution and neutral gas Pressure (puff)

Systematic sharp increase of plasma temperature with number of AC cycles

No impurity accumulation



Impurity contribution and neutral gas pressure (gas puff)



Runaway electron (x-ray signal) seems not reduced by gas puff

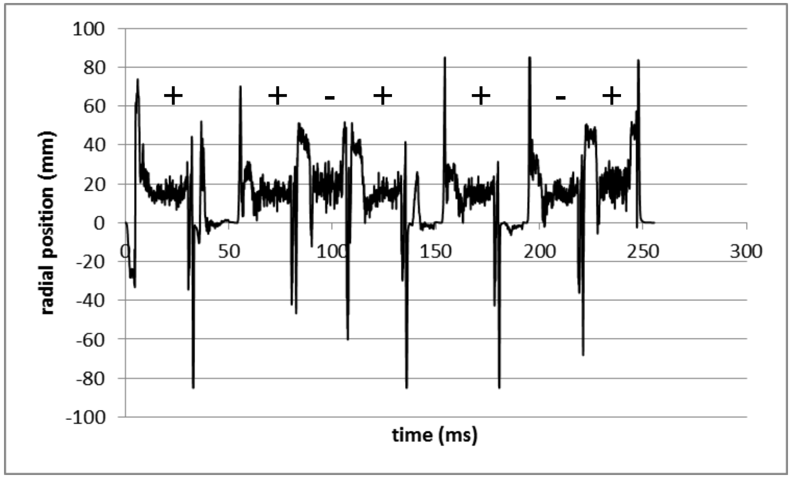
This could be due to the lowering of plasma density and possible presence of hollow temperature profiles (it is noticeable a correlation between x-ray and plasma density:

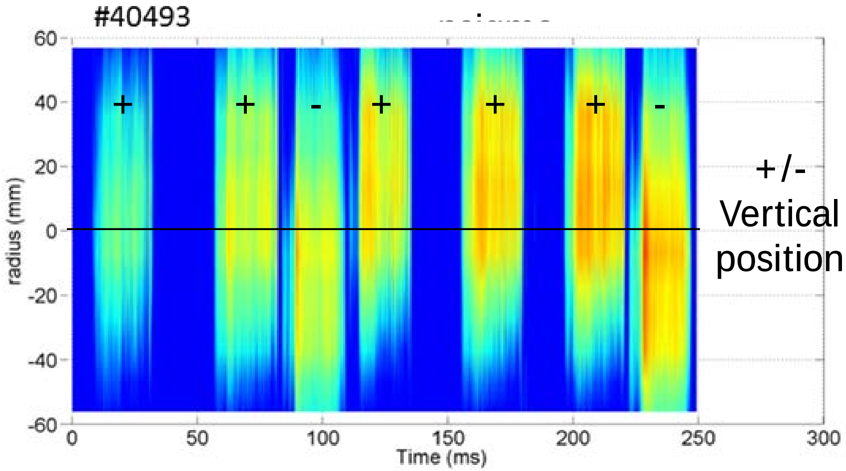
less plasma density → more x-rays

On the other hand, increasing gas puff seems to help to obtain more successful full AC cycles

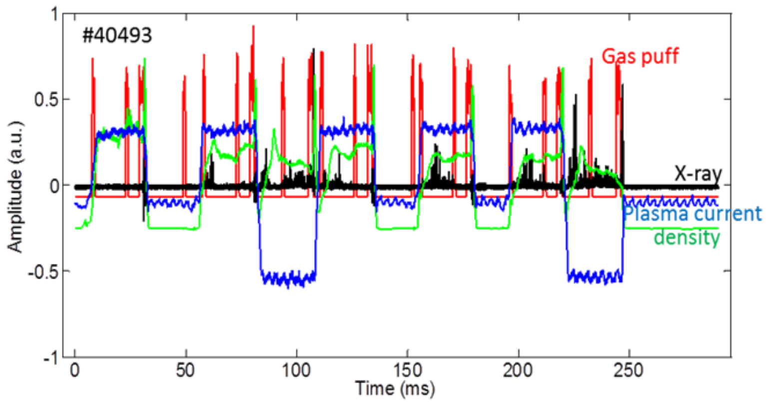
Wider gaps between gas puffs → larger x-ray signal events
(in lower and higher density semi-cycles)

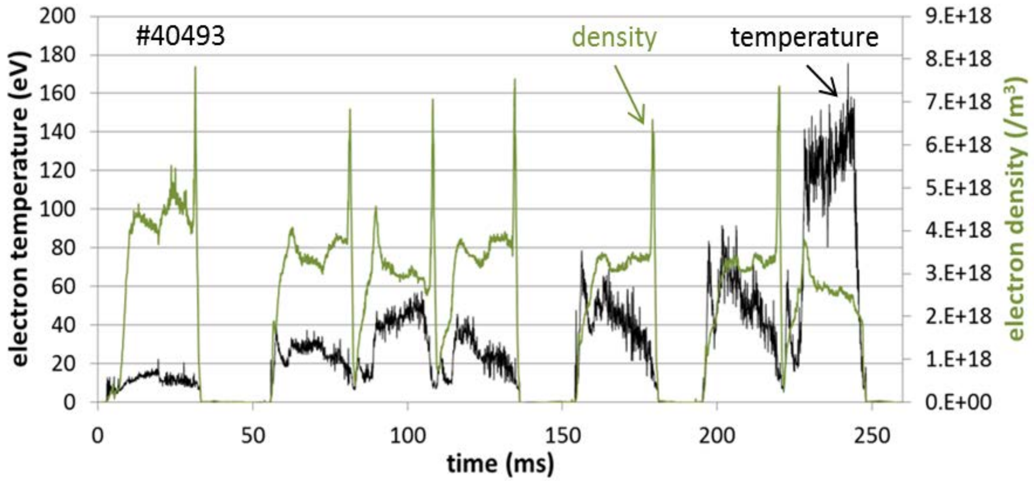
Analysis of #40493





+/-
Vertical position





In using data from interferometer and HIBD the role of plasma vertical shift is not so important

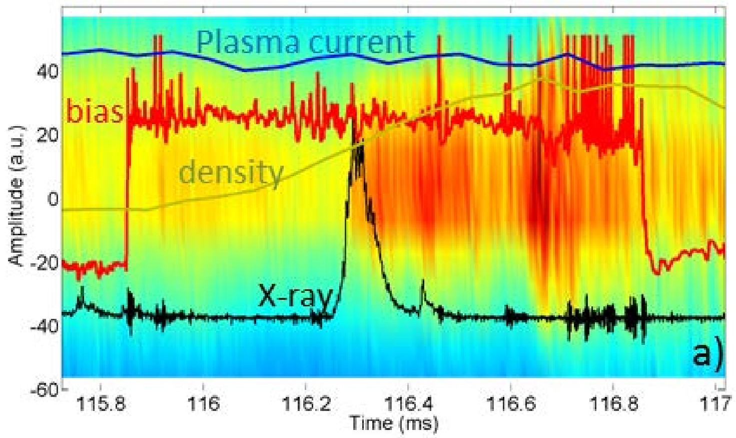
In this shot the horizontal shift is relatively low

Effects of biasing on runaway electrons generation

EB triggers runaway formation → interplay with plasma pressure

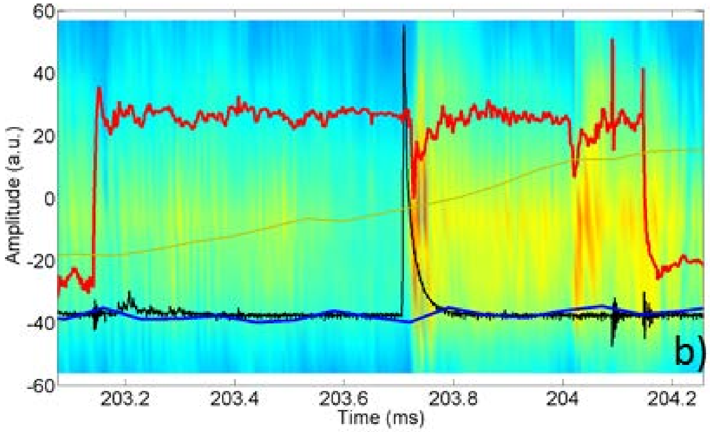
Plasma density increses with biasing but nsigma reduces → temperature drop (typical)

0.6 ms after biasing low temperature triggers runaway formation



- The broader x-ray signal may imply a larger runaway plasma fraction.
- The runaway gradually drifts to the wall
- After runaway vanishes the plasma density and temperature increases

0.6 ms after biasing low temperature triggers runaway formation



- The fast x-ray pulse rise and decay indicates a very localized run away beam (drift to the wall)
- The fast vanishing of the runaway beam induces a transient plasma pressure increase
- This could be attributed to the conversion of runaway beam magnetic energy into a residual plasma current increase

Runaway influence on discharge ramp-up

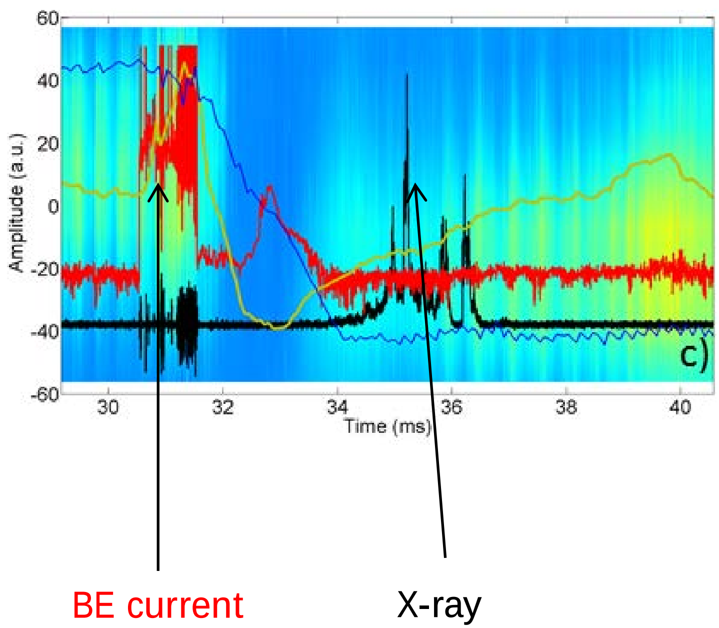
runaway during pressure build-up → possible compromise on plasma discharge performance

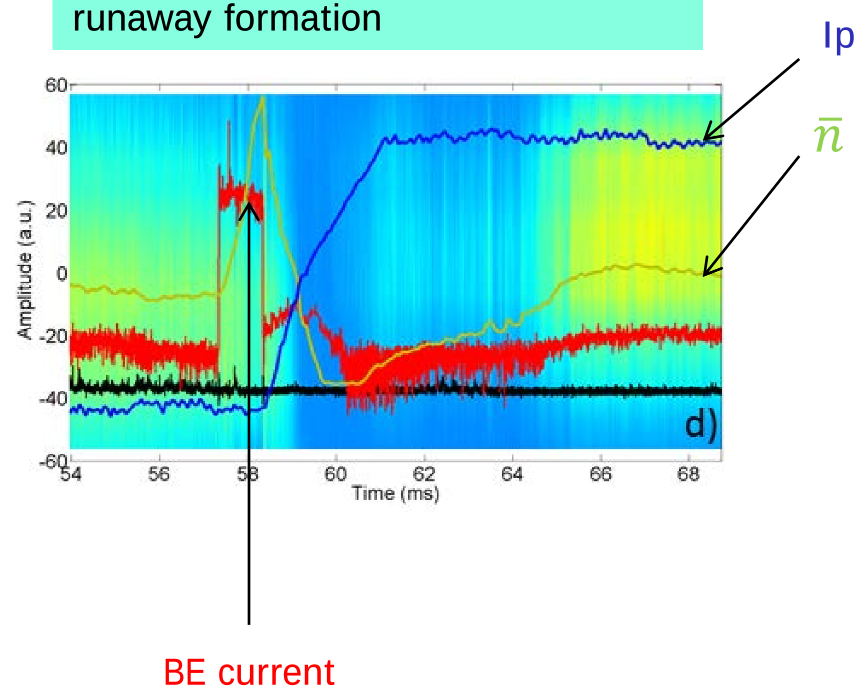
Transition +/-

Ramp-up of plasma pressure presents oscillations synchronized with runaway formation

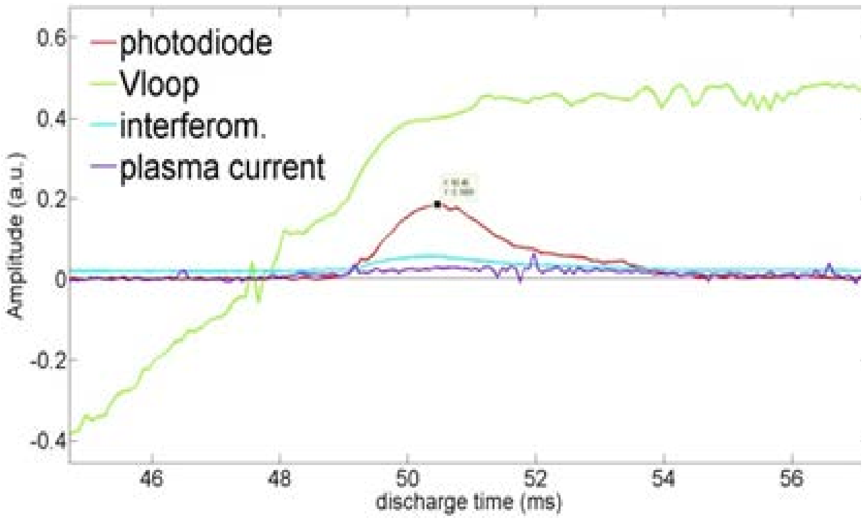
Transition -/+

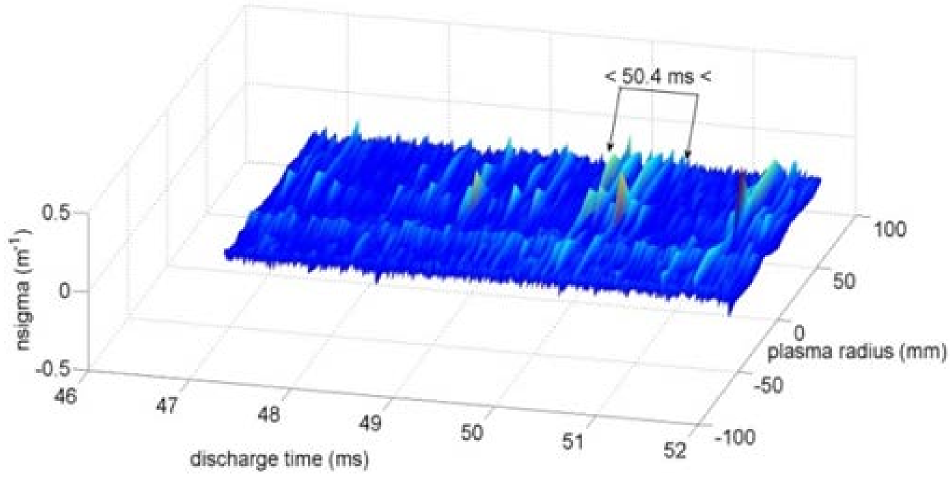
Ramp-up of plasma pressure presents smoother evolution without runaway formation





drift electrons signature:
Non-successful AC transition





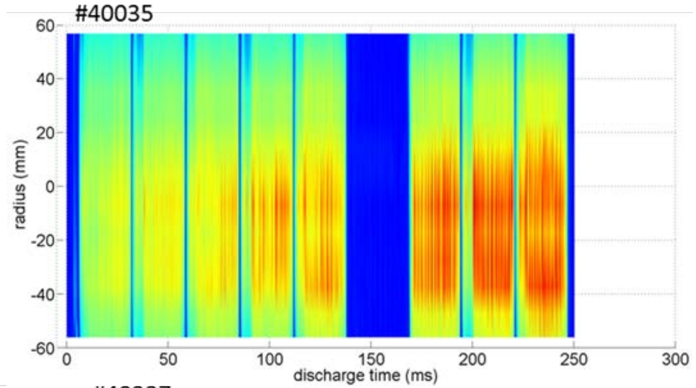
@ 50.4 ms during ramp-up

- Relatively large transient visible emission
- Residual plasma current
- Residual plasma density

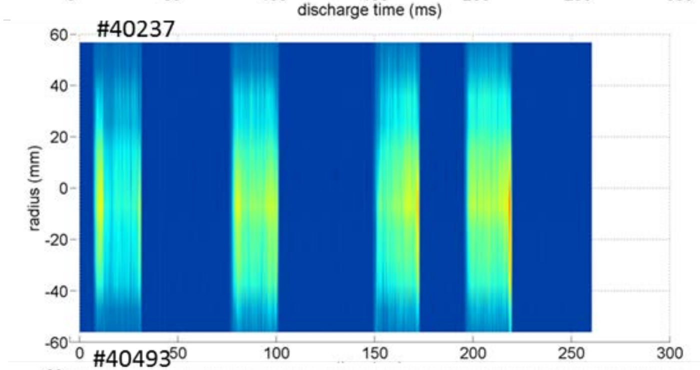
- Residual nsigma detection
- signature of vertically shifted electron density

Electrons seem to drift to the vertical part of the vessel (in agreement with expected drift direction due to gradB)

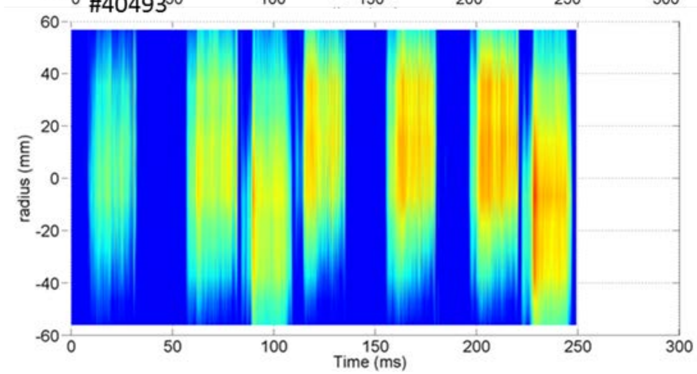
The role of external V/H magnetic fields



#40035: plasma column has an offset of -17 mm vertically but almost all semi-cycles where successful



#40237: plasma column is nearly centred but many semi-cycles have failed

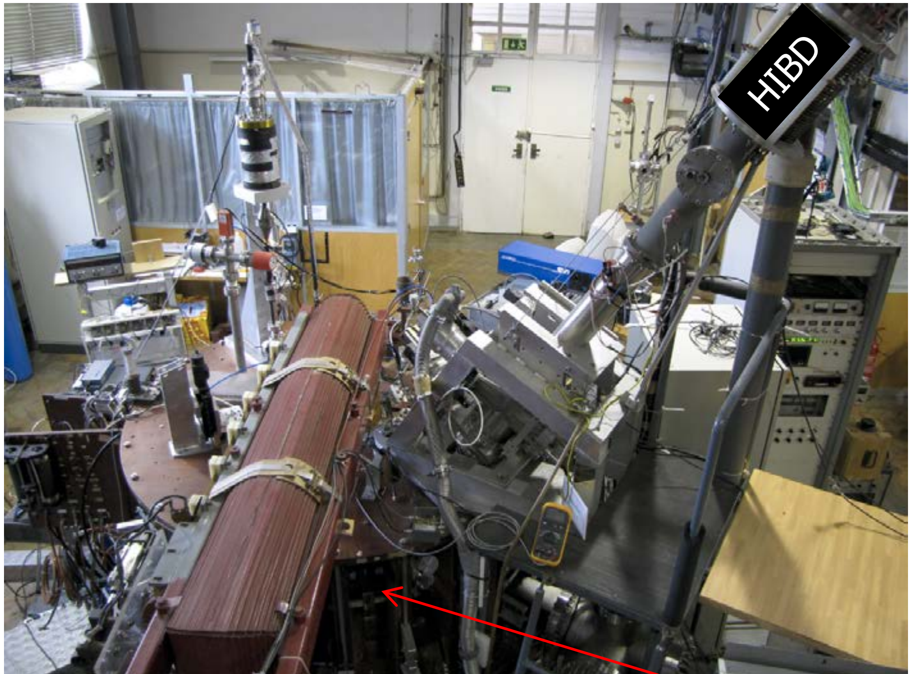


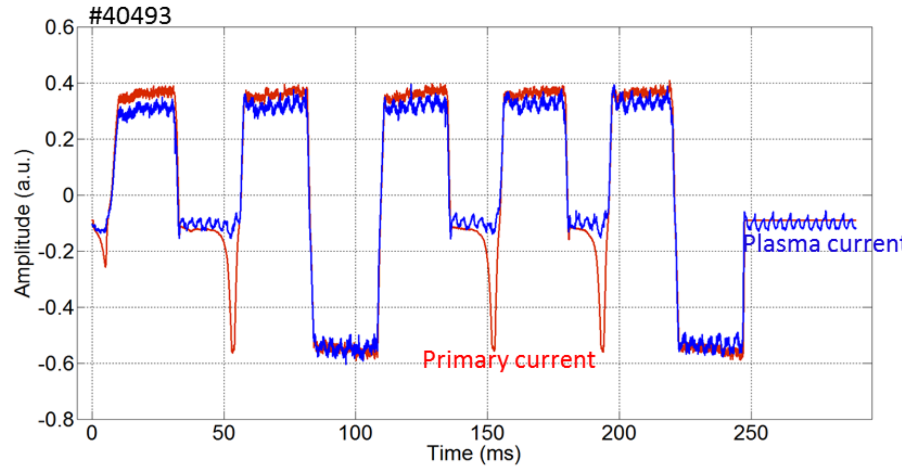
#40493: the plasma column swings up and down of the centered position depending on the plasma current direction maintaining some successful AC transitions

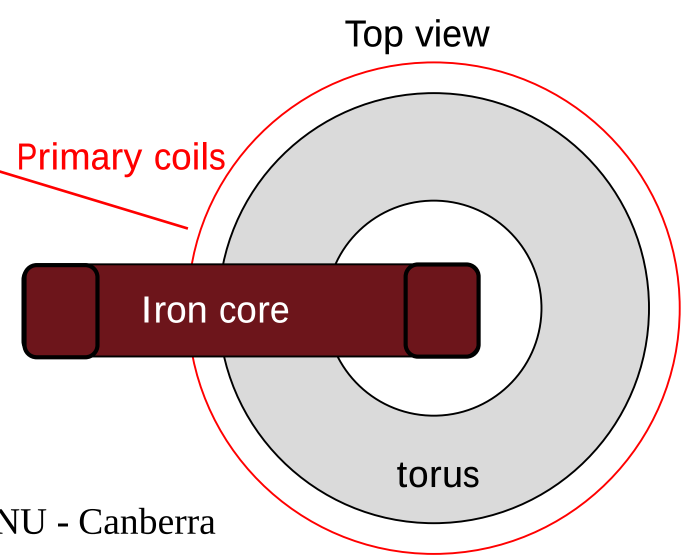
If the plasma fully forms the V/H fields tuning do not influence the progress of the AC discharge (within practical limits)

And what about during burn-through and ramp-up phases – critical phases?

Plasma current during the AC transition

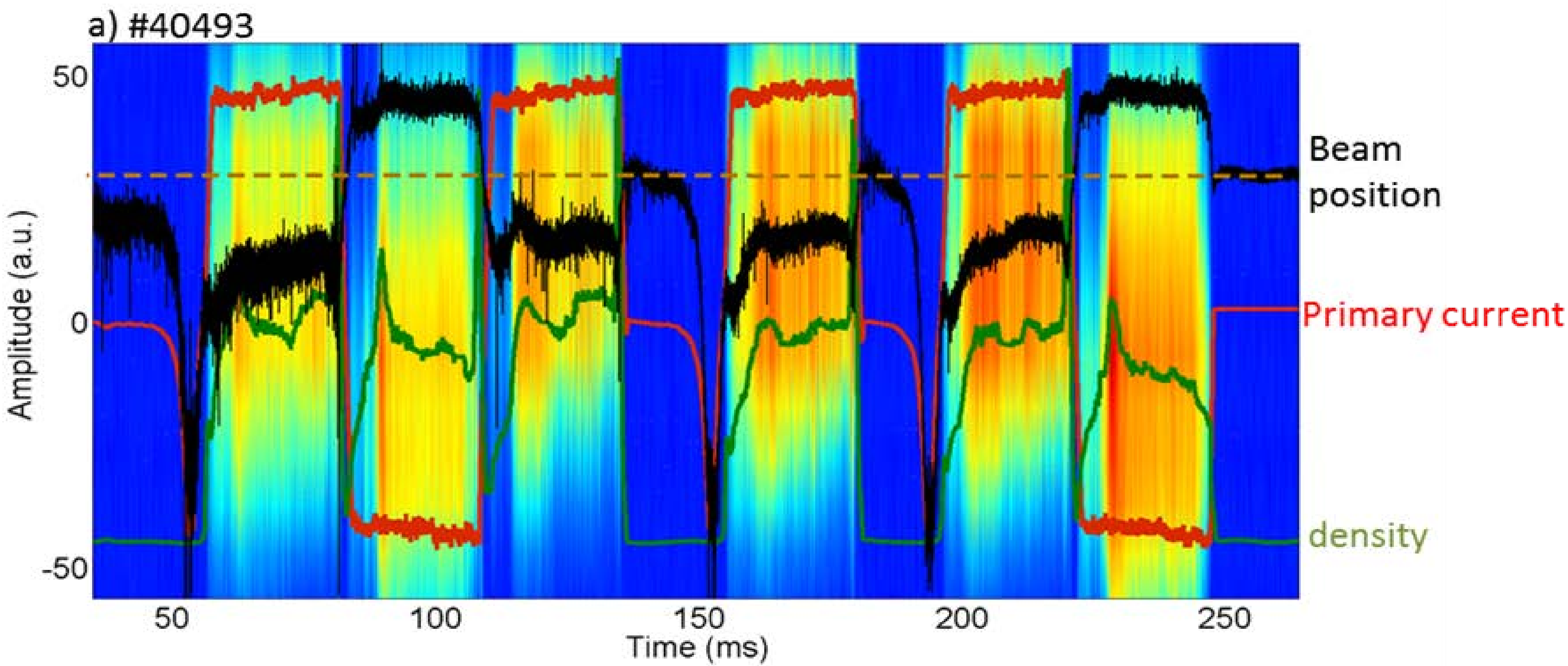






- During discharge the primary current follows the plasma current
- Without plasma discharge the iron core saturates towards the end of the semi-cycle
- During saturation the primary coils current increases and also the ‘free air’ magnetic field

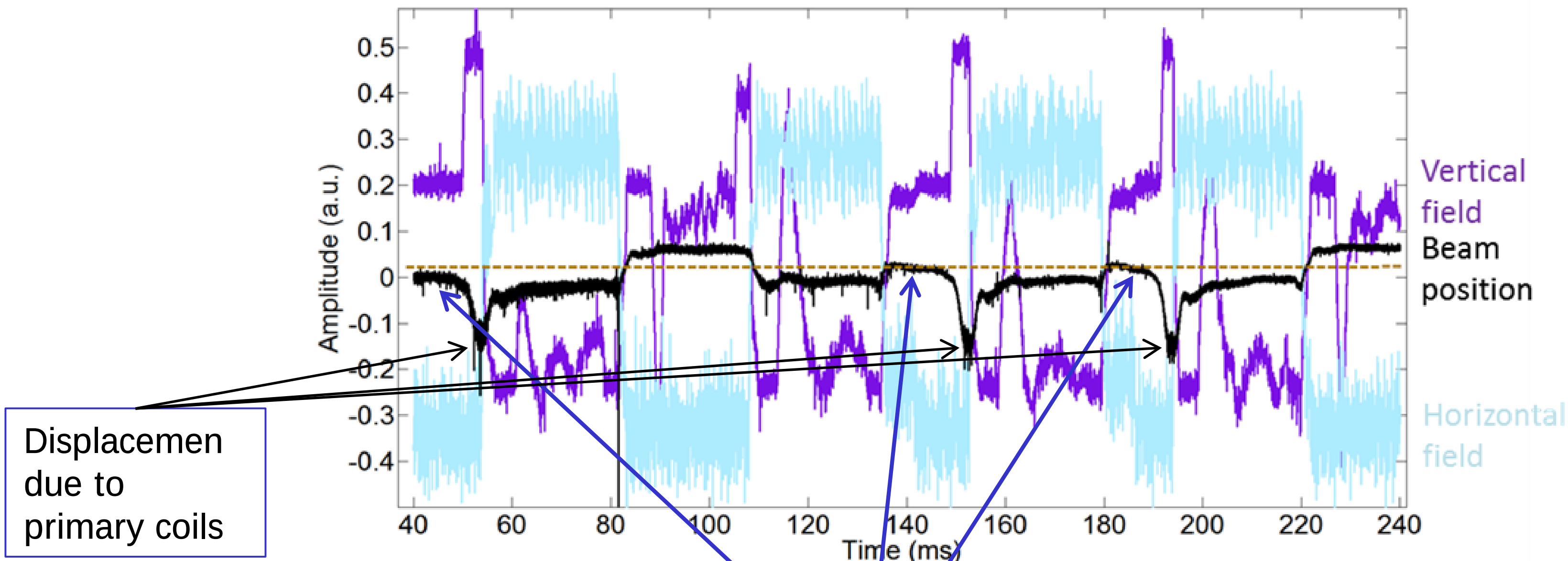
Plasma current during the AC transition



- The primary beam position (in the toroidal direction) is proportional to the total plasma current
- When there is plasma the beam position follows by enlarge the plasma current
- When there is no plasma the beam position follows the ‘free air’ magnetic generated by the primary coils

Plasma current during the AC transition

Vertical and horizontal plasma position control magnetic field

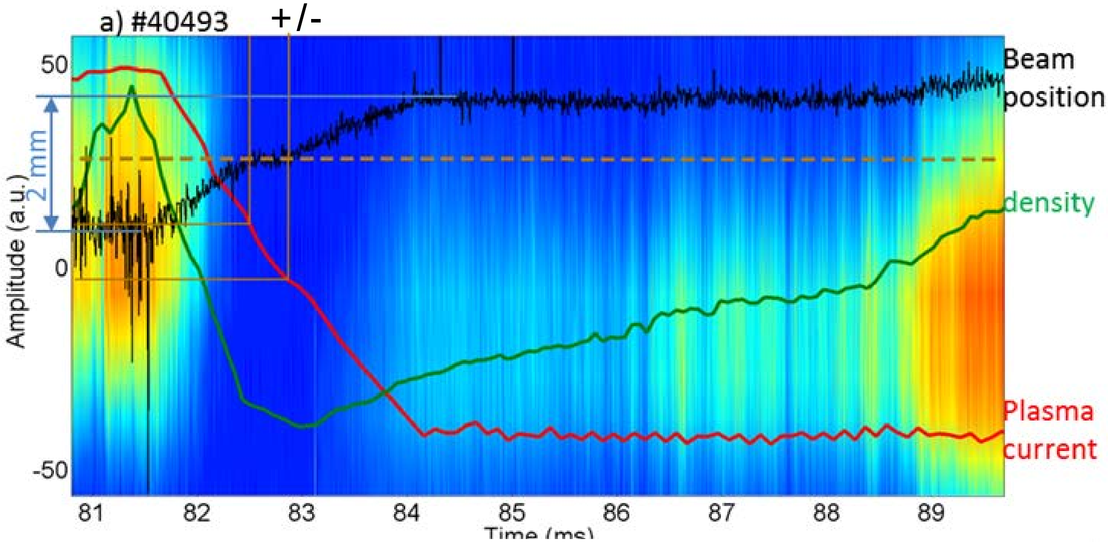


As observed for when there is no plasma:

The effect of H/V field is negligible in the primary beam position

during discharge the beam toroidal position is by enlarge determined by the plasma current

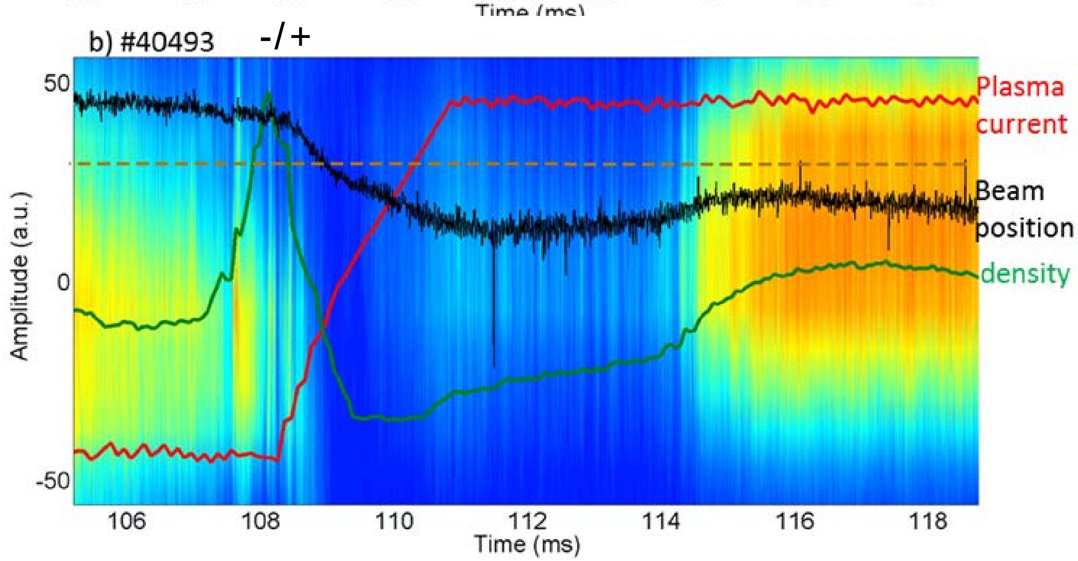
Plasma current during the AC transition



Beam toroidal shift accuracy = +/- 280 A

sensitivity = 0.25 mm/KA

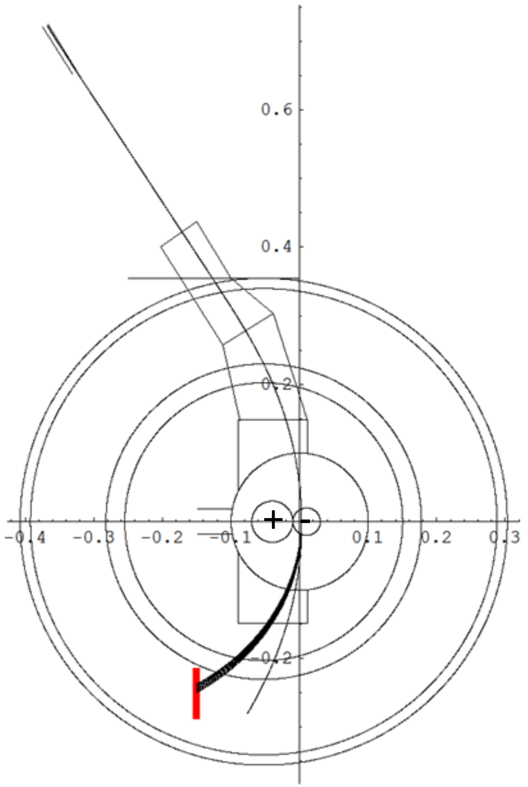
- The beam position follows the change of plasma current
- Near the point of current inversion the beam position stays frozen for 0.4 ms
- During this time the plasma current changes by 800 A



- The beam position follows the change of plasma current but with a different evolution than above
- During initial stable current phase (111-114 ms) the plasma pressure and density are still evolving
- During this phase the beam position evolves indicating a current density profile change (flat profiles generate larger shifts for the same plasma current)

Plasma current during the AC transition – double current channel?

Two opposite plasma currents inducing a low beam toroidal shift



+ 0.7 kA – 0.5 kA = 0.2 kA (net)

Δz = - 0.1 mm

- The presence of 2 counter current channels during Ip transition has been measured in the CT-6B tokamak
- The results from ISTTOK show a freeze of the HIBD toroidal beam shift for 0.4 ms during current inversion (it could be compatible with the formation of two counter current channels)
- As for the -/+ transition the beam shift seems to indicate a plasma current evolution from flat to peak profile

Conclusions

- During AC operation it is observed that a quescient plasma is maintained for up to 0.8 ms after the unsuccessful AC transition, which is longer than ISTTOK confinement time (0.3-0.4 ms).
- Electrode biasing experiments have demonstrate that it is possible to increase the plasma density during the AC transition (when $I_p = 0$) roughly from 30%-40% above the non-biased cases.
- The increase of density via EB did not translate into a higher success rate of full AC cycles
- We observe that the use of bias electrode to increase the density at the AC transition causes a reduction of the electron temperature leading to the production of runaway electrons that show an interplay with plasma pressure.
- The presence of runaway electrons was detected during plasma pressure build-up phase and showed to influence the plasma evolution
- The presence of a drift-electrons-like population was also detected in some particular shots
- Gas puff in controlled doses can help to increase the number of AC semy-cicles: what dose? n? T?
- The current evolution during AC transition was measured by HIBD and indicated some non-linear features that could be compatible with the presence of a double counter current
- Current density profile changes from flat to peaked could justify the observed changes on HIBD beam position @ constant Ip

The experimental data available may be used to support the development of a first order predictive model that could integrate the observed results and inform on the interplays between different plasma parametrs

Work in Collaboration

Three phases of the AC transition that can be proposed:

1. Transition from full to null current, from when Vloop swings to Ip=0
2. Quiescent plasma and ramp-up
3. Burn-through and full plasma development

1. – Treat like a disruption? What kind?

- how does the plasma evolve while the flux swings direction?
- Up to when during the transition there is equilibria?
- Two counter currents formation?

2. – Treat like could plasma? (neutral population?)

- What keeps the quiescent plasma?
- What external control parameters are important for the good ramp-up of plasma current?
- What are the optimal quiescent density an temperature for successful plasma ramp-up?

3. Treat like a partial evolving plasma with important runaway population

- What is the role of runaways and how to mitigate their presence or effects on plasma development
- What is the role of fast electrons?

ETC,

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