# Overview the CASTOR "Fast Particles" experiments

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**outline:**

- **motivation**
- **theory prediction**
- **CASTOR and experiment set-up**
- **measurements with cold double probes having tips spaced 3.5mm in toroidal or poloidal direction [1]**
- **comparison of floating potential of the cold and the emissive probe [2]**
- **Conclusions**

**[1] Contrib. Plasma Phys. 44 (2004) 635**
**[2] 12th ICPP, Nice Oct 2004, P1-70**

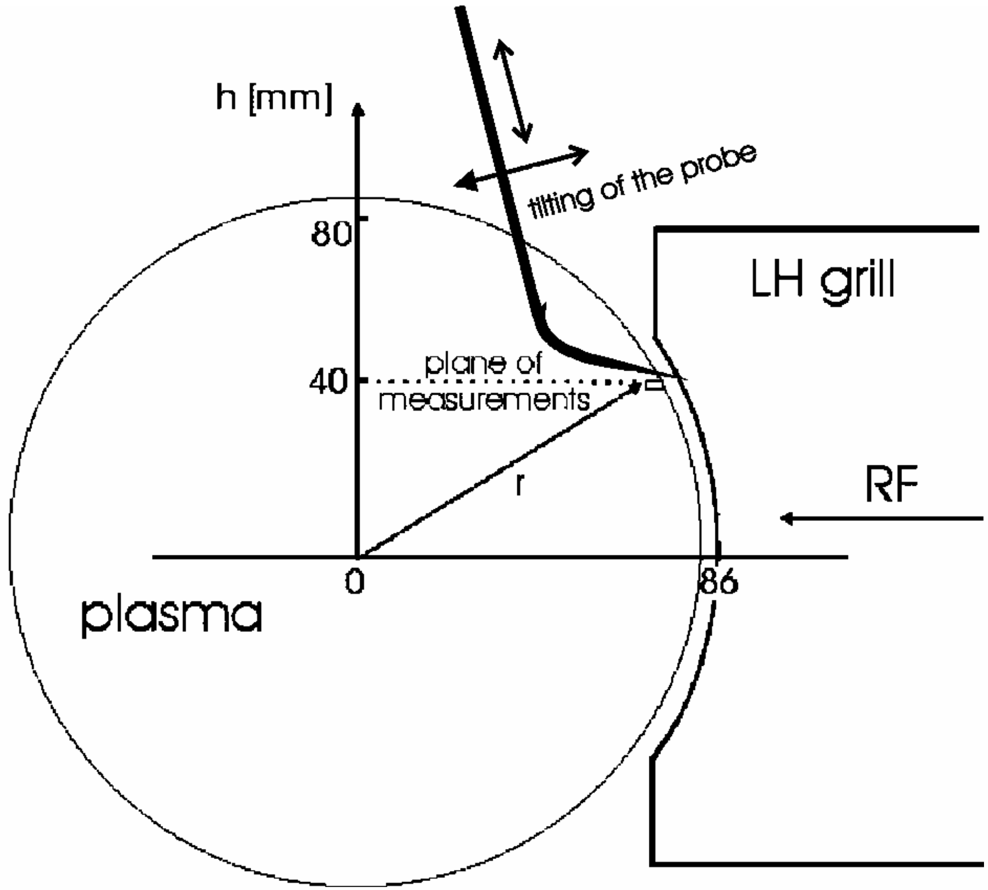
# Motivation

- **Lower hybrid waves (*LHW*) are used for non-inductive current drive in tokamaks.**
- **However, additionally to the current drive itself, resulting in favourable effect on the plasma stability, a detrimental phenomenon of particle acceleration (up to energy of several *keV*) in the region just several *mm* in front of the *LH* antennas is observed.**
- **Such particles represent a potential danger for those plasma-facing components, which are magnetically connected with the region of particle acceleration, especially if *LHW* power of *MWs* order is used.**
- **Strongly localized erosion of some elements of the first wall has been already found and creation of so called "hot spots" have already been observed in tokamaks JET and Tore Supra).**

# Theory predictions:

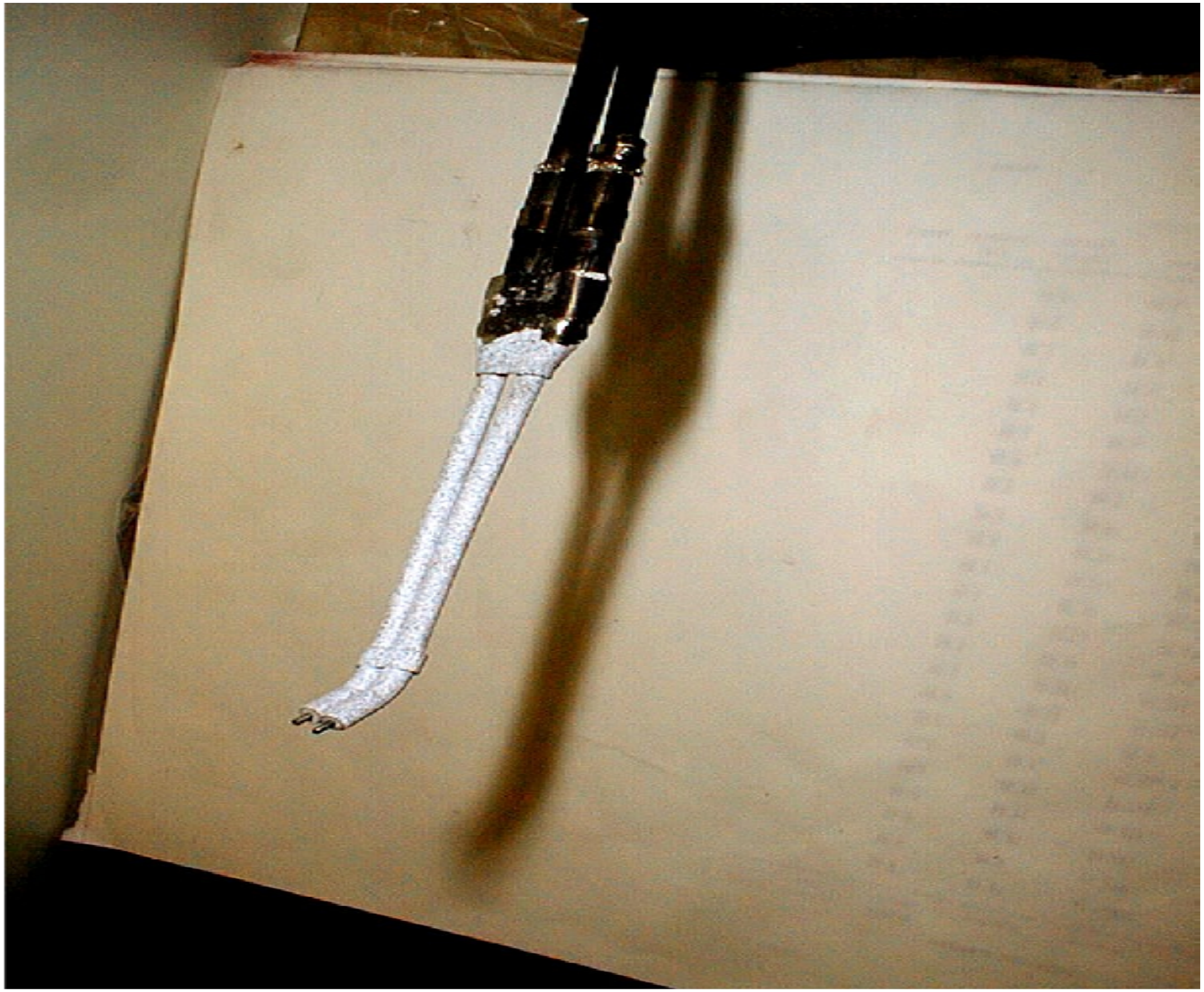
- As a primary mechanism of the observed parasitic effect the theory suggests a local acceleration of the electrons in direction along the magnetic field lines.
- An escape of these accelerated electrons results in a charge separation and plasma positive biasing.
- The positive plasma biasing accelerates the plasma ions (these ions are then probably responsible for erosion of material parts, connected directly with interaction region by magnetic field lines).
- However, a direct experimental proof of such mechanism has not been given up to now.

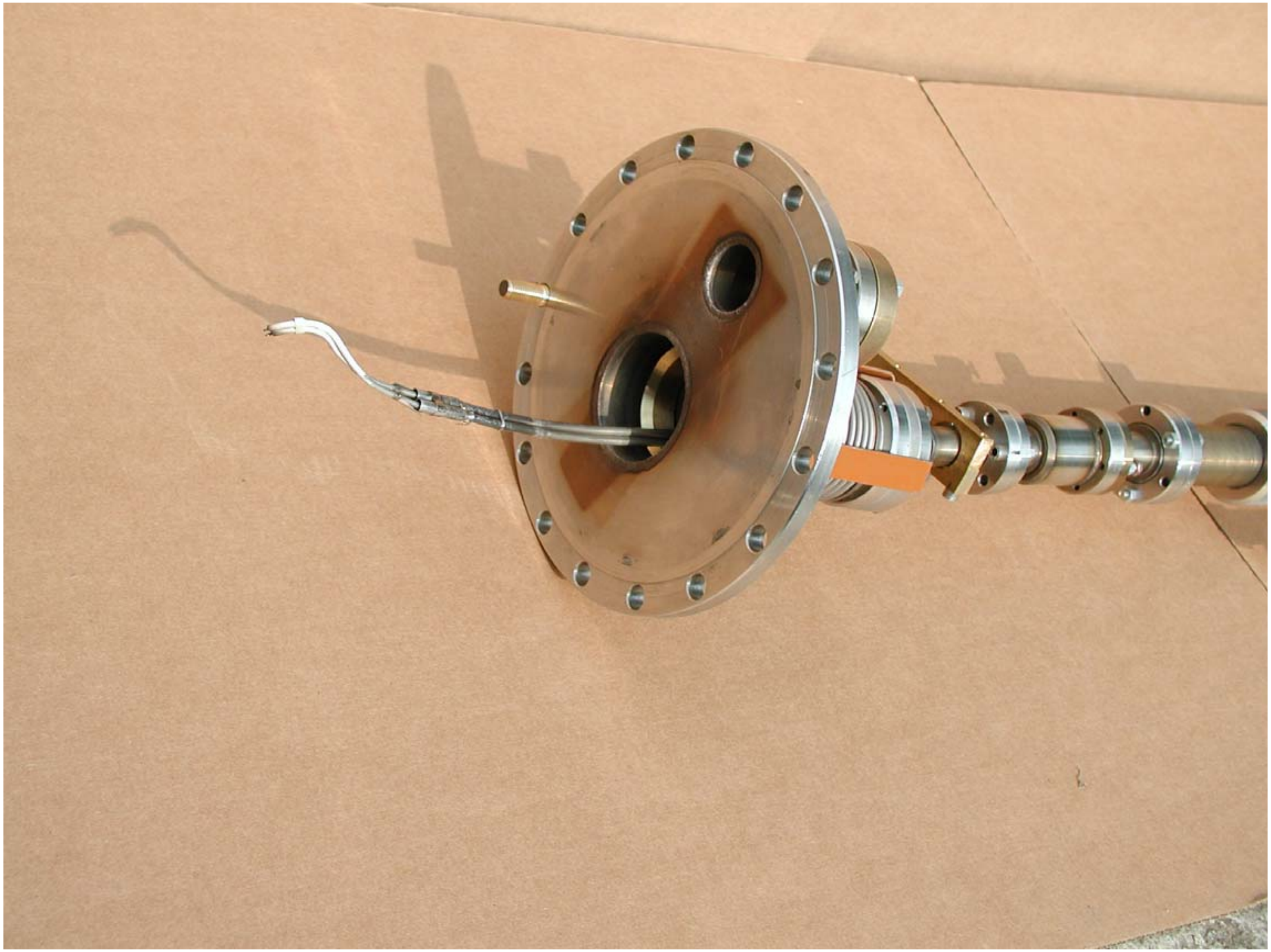
[1] Fuchs V. et al., Phys. Plasma 3 (1996) 4023
[2] Petržílka V. et al.: 18th IAEA Conf., Sorrento 2000, paper CN- 77/EXP4/07
[3] Petrzilka V. et al., 29th EPS Conf., Montreaux 2002, P2.105



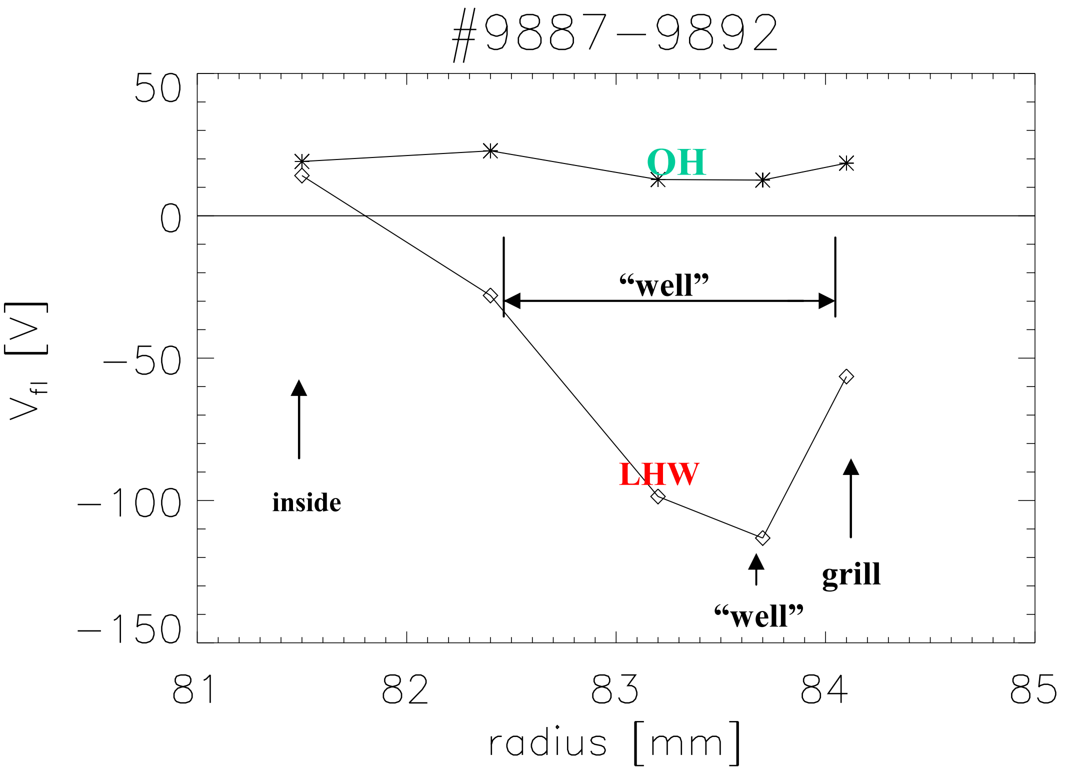

***Schematic of CASTOR small cross-section with the lower hybrid grill (radius of the grill circular shaping is 86mm, aperture limiter radius is 85mm).***

***Double coaxial probe with tips spaced 3.5mm in toroidal direction, coated by plasma sprayed corundum.***





***Double coaxial probe with tips spaced 3.5mm in poloidal direction, coated by plasma sprayed corundum.***




***Radial profiles of the time averaged floating potential in OH (asterisks) and LHW (diamonds) discharge phases (h=40mm, toroidally spaced probes).***

## *A) main results obtained using two <u>toroidally separated probes</u> tips measuring $V_{fl}$:*

- **maximum of the $V_{fl}$ cross-correlation function reaches all the time value nearly one during OH (i.e. there is hardly any measurable toroidal electric field),**
- **the cross-correlation during LHW:**
  **(i) is going to zero (or becomes sometimes even negative) deeper in the plasma,**
  **(ii) remains very high and an expressive long-living frequency component about 50kHz appears just in the potential "well (confirmed also directly by FFT of the $V_{fl}$ signal);**
  **(iii) simultaneously with recovering of the cross-correlation in the "well", a time shift order of 1µs of the maximum appears in this region (indicating a one-directional toroidal movement of the fluctuations in the "well" with a velocity several km/s in direction of the parasitic spectrum);**
- **taking difference of $V_{fl}$ signals of the probes (distance 3.5mm), a substantial <u>increase of $E_{tor}$</u> during LHW at all radial positions has been found;**
- **this amplitude increase is caused by a massive enhancement of the low frequency component of the spectrum;**
- **while $E_{tor}$ has character of a broadband noise during OH (especially deeper in the plasma), its spectrum exhibits a "massive" low frequency part in RF;**
- **this distinct difference is not in any case the most profound in the "well";**
- **this fact could indicate that <u>toroidal electric field participates in the particle acceleration</u> in this very narrow layer and, in this way, it is absorbed there;**

## *B) main results obtained using two* *poloidally separated tips* *($V_{fl}$ an $I_{sat}$):*

- **there is a stable poloidal velocity shear layer during the OH phase (with radius about 78mm);**
- **this shear layer is evidently shifted more to the periphery during the LHW phase because there is no apparent difference between OH and LHW phase deeper in the plasma, while a substantial difference is observed just in the $V_{fl}$ "well": here the sense of the fluctuations rotation is changing with LHW application and the correlation itself is much smaller (quite disappears at radii greater as the "well");**
- **this observed shift of the shear layer to the grill, as well as increase of $V_{fl}$ in this region, are in concordance with theoretical predictions about an increase of the plasma potential in the interaction region, ensuing from electron acceleration and their successive run out;**
- **LHW pushes the plasma 1-2mm out of the CASTOR grill (and generally decreases density fluctuation); such plasma pushing has been already predicted by theory and observed e.g. in ASDEX device;**
- **the cross-correlation function between plasma density and floating potential varies substantially (and probably radial transport also) with the radius for the both OH as well as LHW discharge phases;**
- **however, radial dependence of the cross-correlation function differs significantly for OH and LHW:**
  **while hardly any difference is observable deeper in the plasma (i.e. no effect of LHW is observed), it acquires totally another character starting with approaching to the potential "well"; from this fact a strong effect of LHW on the transport properties just in this region can be deduced.**

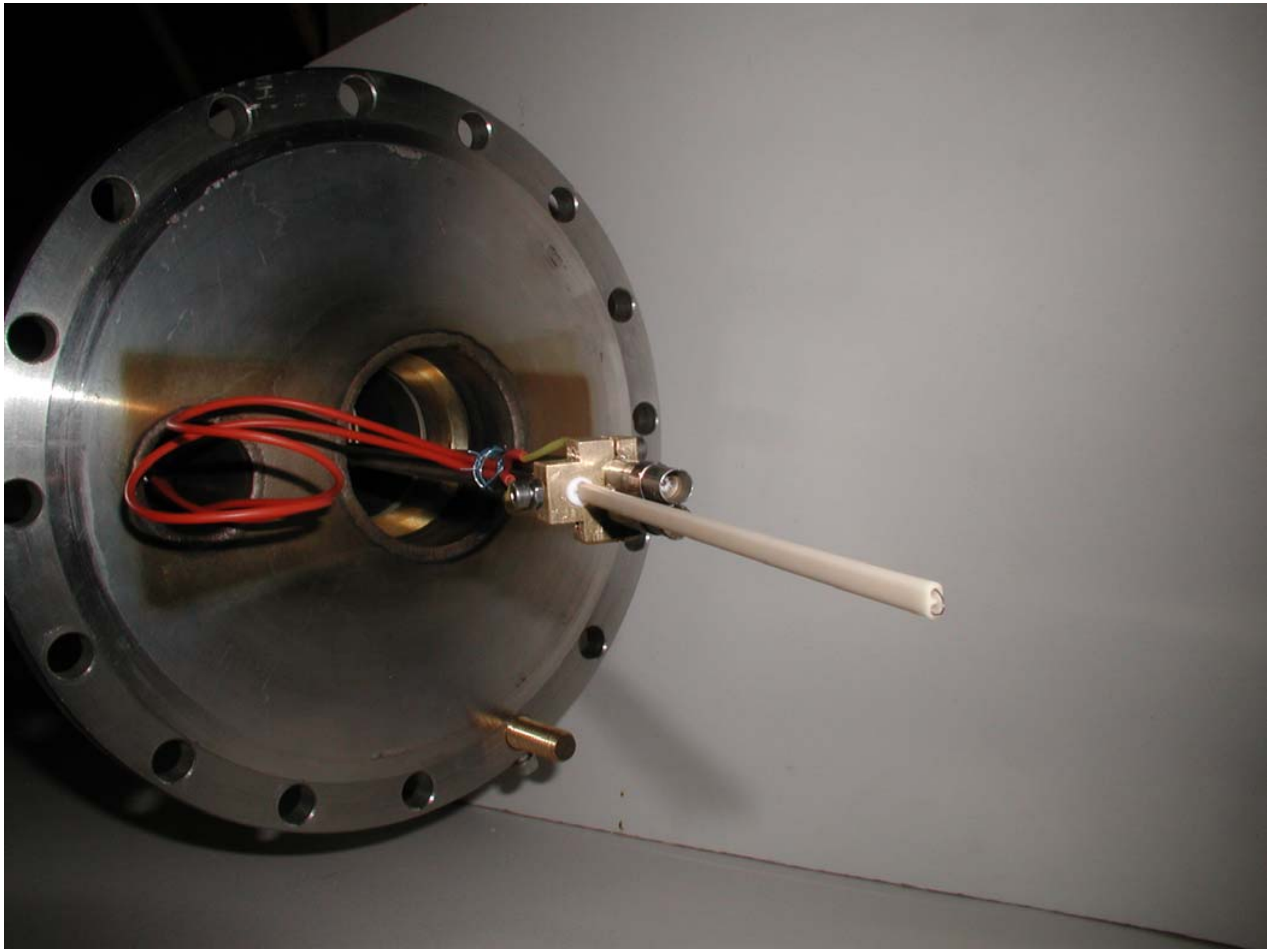
## Experimental set-up of the heated probe:

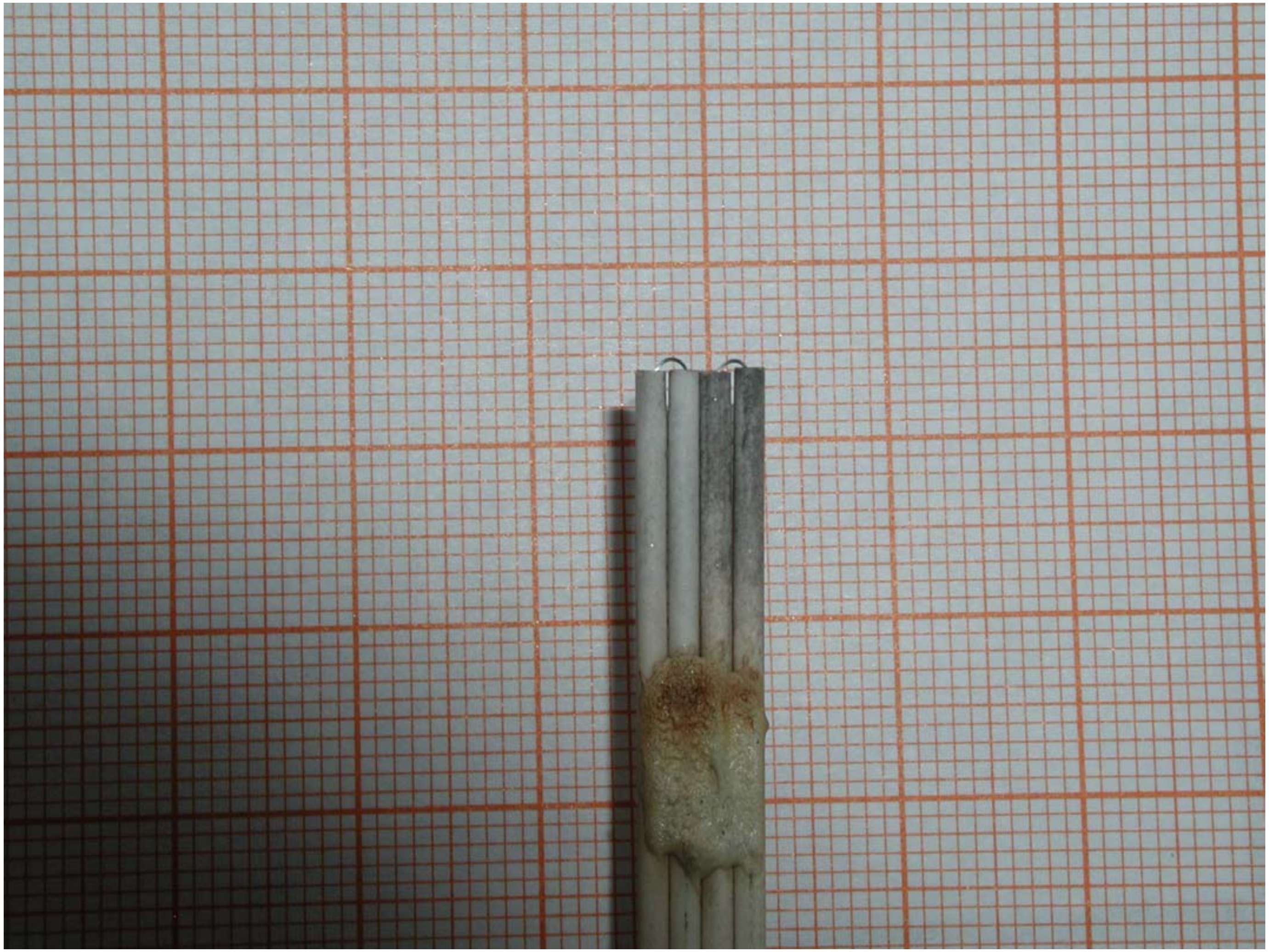
- For measurement of the real plasma potential a floating, but emissive (heated to the temperature more as 2500 $^{o}$C) Langmuir probe has been used [*];
- Probe consists of a small loop of thin tungsten wire with diameter *0.2mm*, heated by DC current *7A* (current *6A,* heating the probe to the temperature 2300 $^{o}$C only, has not been sufficient*);*
- The plane of the probe loop is placed on one magnetic surface, to assure a high radial resolution;
- The probe is radially movable (by tilting from the top of the tokamak) in front of the central grill waveguide of the grill;
- Due to a good reproducibility of the CASTOR discharges, radial profiles of the probe floating potential can be obtained on the shot-to-shot basis, both in the cold as well as in the heated probe state;
- The signals are sampled with 1MHz frequency;

[*] Schrittwieser R et al. 2002, "Measurements with an emissive probe in the CASTOR tokamak", Plasma Phys. Contr. Fusion 44, 567-578

Balan P et al 2003, “Emissive probe measurements of the plasma potential fluctuations in the edge regions of tokamaks”, Rev. Sci. Intr. 74, 1583-1587

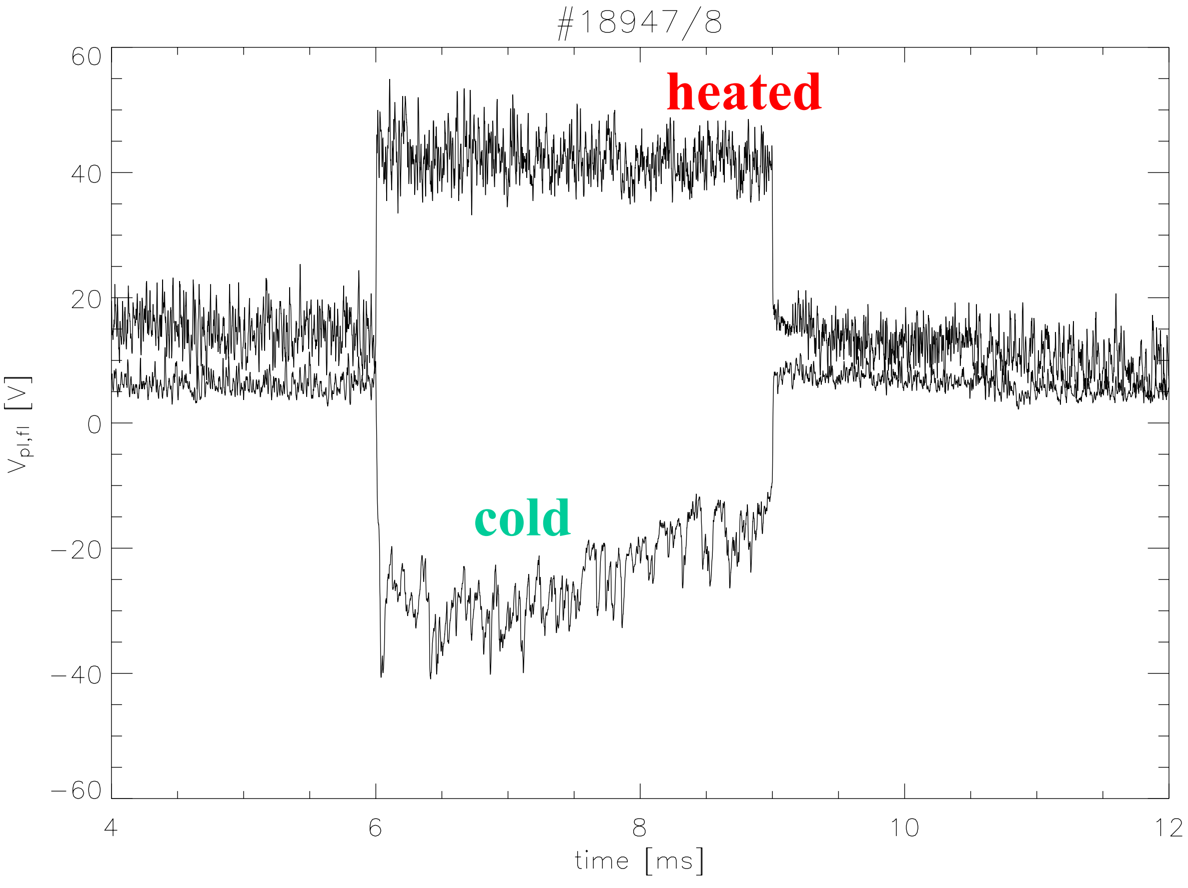
*Emissive probe with loop of tungsten wire diameter 0.2mm, protected by a corundum tube with double hole.*



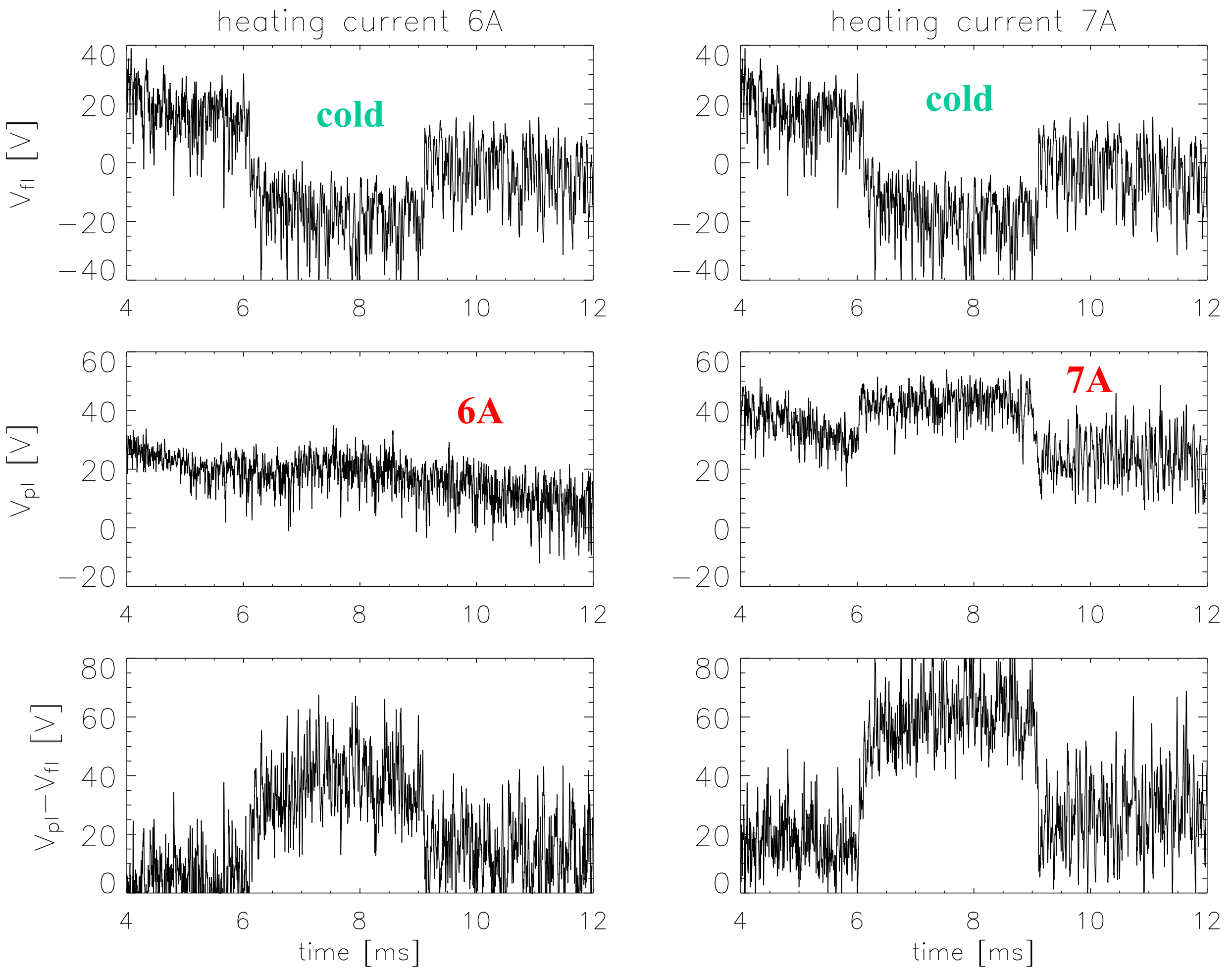


***Double emissive probe with loop of tungsten wire diameter 0.2mm, formed by 4 corundum tubes with diameter 1.65mm***

**Floating potential measured by heated (electron emitting => $V_{pl}$) and cold (not emitting => $V_{fl}$) Langmuir probe**

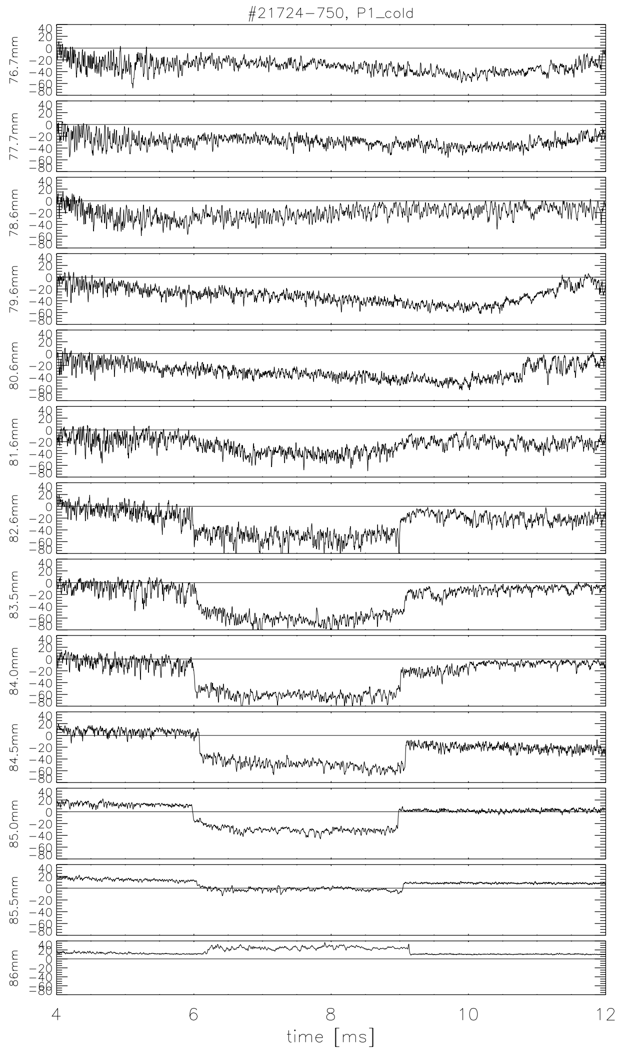


# Time dependence of the floating potential of cold (Vfl) and emissive (Vpl) probe with two different heating currents 6 and 7A (LH wave is applied between 6 and 9ms)

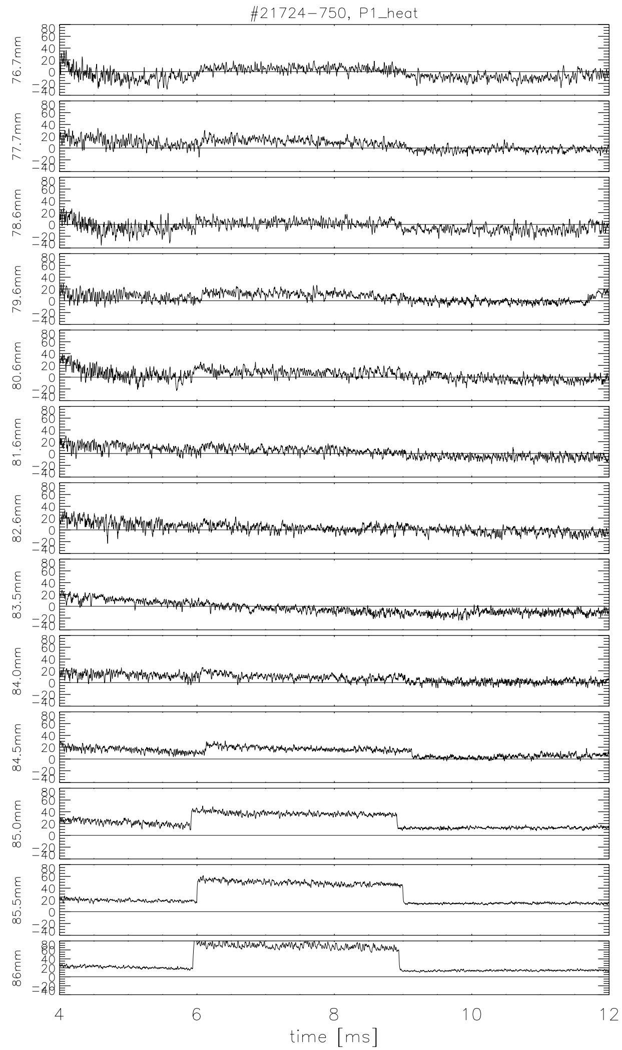


# Comparison of a) cold and b) emissive probe floating potentials during OH and LHW application (between 6th and 9th milliseconds) on different radii in front of the CASTOR grill

## a) cold -> Vfl



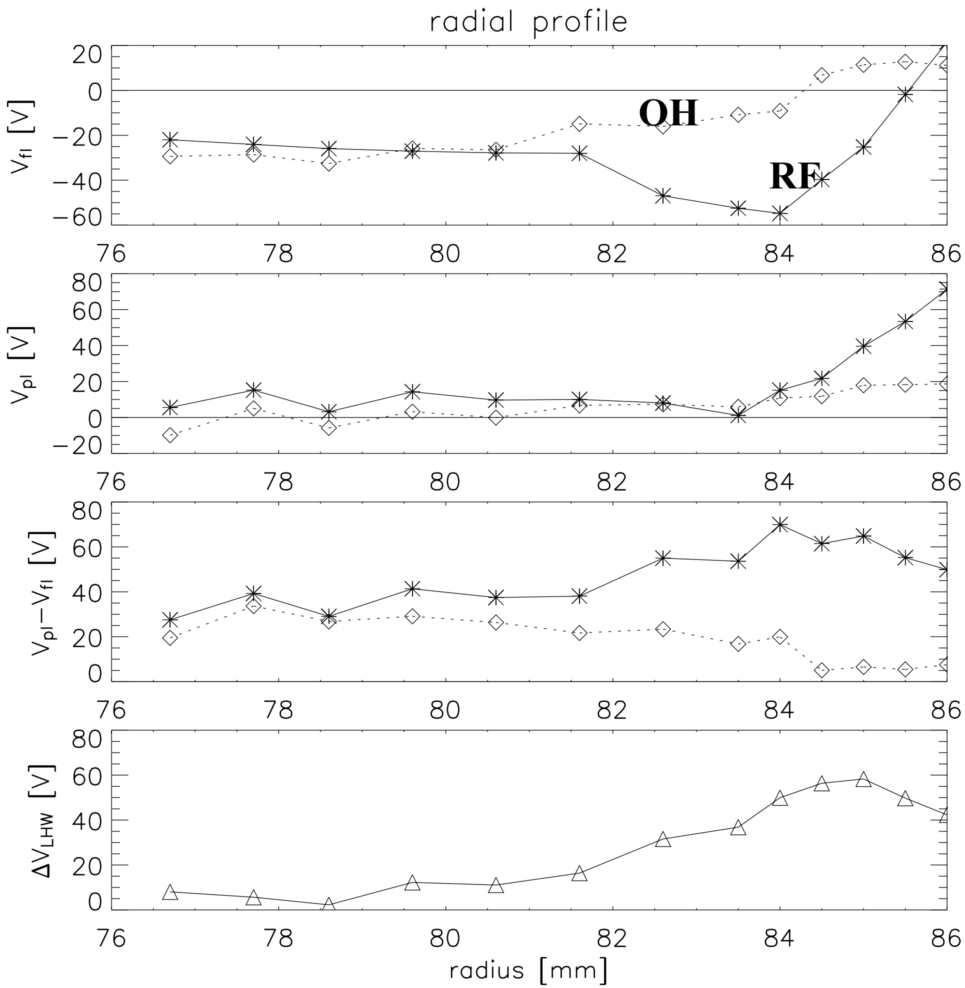

## b) emissive -> Vpl



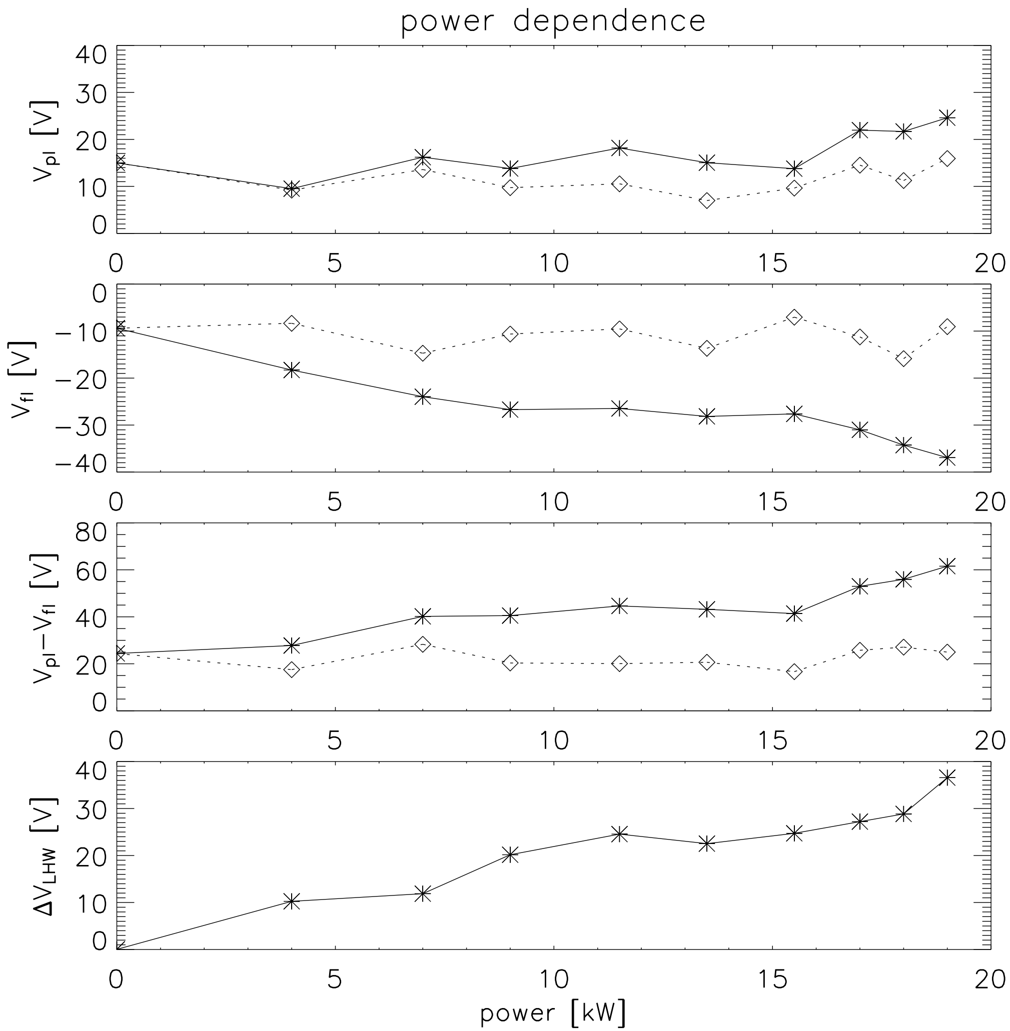
**Comparison of radial profiles of the cold ($V_{fl}$) and emissive ($V_{pl}$) probe floating potentials in OH (diamonds) and LHW (asterisks) discharge phase.**
**Difference of both potentials $V_{pl} - V_{fl}$ is shown also.**
**The last trace denoted as $V_{LH}$ (triangles) is a net change of $V_{pl} - V_{fl}$ due to the LHW with respect to its ohmic value.**

**cold**

**heated**



**Power dependence of the LHW effect measured by the probe in the potential “well” of the probe floating potential (r=85mm)**



# Measurements and evaluations carried out:

- **Using movable Langmuir probe, time behavior of the probe floating potential has been measured in front of the CASTOR Lower Hybrid grill antenna.**
- **On shot-to-shot basis broad radial dependences of time averaged floating potentials of cold (floating, denoted as $V_{fl}$) as well as emissive (heated over 2500 $^{o}$C, denoted as $V_{pl}$) have been obtained.**
- **A linear dependence of the effect on the *LHW* power has been found.**

## Results obtained:

- The measurements with non-emissive probe (i.e. without probe heating) confirmed formation of a negative “well” on the profile of floating potential during *LH* discharge phase, observed already on CASTOR tokamak before and interpreted as existence of a group of electrons accelerated to the corresponding over-thermal energies.
- Radial width of this “well” is less than 4mm and its minimum is localized about 2mm in front of the grill mouth.
- On the other hand, floating potential of the probe heated to the temperature over 2500 $^{o}$C (i.e. the probe becomes to be emissive) exhibits near to the grill an expressive increase if LHW is applied.
- This increase of the emissive probe floating potential is localized still closer to the grill mouth as the “well” of the cold probe floating potential. It starts to be observable at a distance 2-3mm from the grill and increases till the grill mouth itself

- **If we consider this measured potential to be the plasma potential, formation of a strong radial electric field nearly *30kV/m* can be derived in this radially very narrow layer just in front of the CASTOR grill at *LHW* power *20kW* used.**
- **Shear velocity layer, formed under such strong electric field, can result in substantially changes in the transport coefficients in this region, see recent measurements carried out on CASTOR by a double Langmuir probe with two poloidally separated tips *) .**
- **A transport changes in the edge region are accompanied by a routinely observed improvement of global particle confinement in CASTOR).**
- **Dependence of the effect on the *LHW* power, characterized as difference of the floating potentials heated and cold probe in *LH* and *OH* plasmas, seems to have a linear character, i.e. still much higher radial electric fields can be expected in front of antennas launching power of *MWs* order.**

***) Contrib. Plasma Phys, 44 (2004), 635**