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2D distribution of plasma potential and density in the ECRH and NBI plasmas in the TJ-II stellarator

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ABSTRACT

- 2D plasma potential distribution was measured in the ECRH plasmas of TJ-II for the first time in a wide area of poloidal cross-section.
- Equipotential lines are consistent with vacuum magnetic flux surfaces, 2D potential distribution is symmetric with a maximum at the plasma center
- Plasma potential and density RMS are not fully symmetric, effect is stronger for low-density case: at the mid radius (area of the maximum density)
  RMSϕ~15V at LFS vs ~20V at HFS, RMS $\delta n_e/n_e$~2% at LFS vs ~ 3% at HFS.
- **TJ-II plasmas well diagnosed by HIBP present unique platform for the validation of the theoretical models for transport and turbulence in 3D devices**

BACKGROUND

- 2D mapping is aimed to validate the recent theories and GK modeling predicting the poloidal symmetry breaking for plasma potential and density turbulence [1].
- The first experiments aimed at obtain the 2D distribution of plasma potential were performed in TJ-II using Heavy Ion Beam Probe (HIBP) with the variation of Cs+ probing beam plasma entrance angle and energy in the range **128-148 keV** [2].
- Comprehensive study to characterize 2D structures of plasma potential and density mean-value distributions and fluctuations in TJ-II has been recently performed by varying the beam energy in a wider range **100-150 keV**.

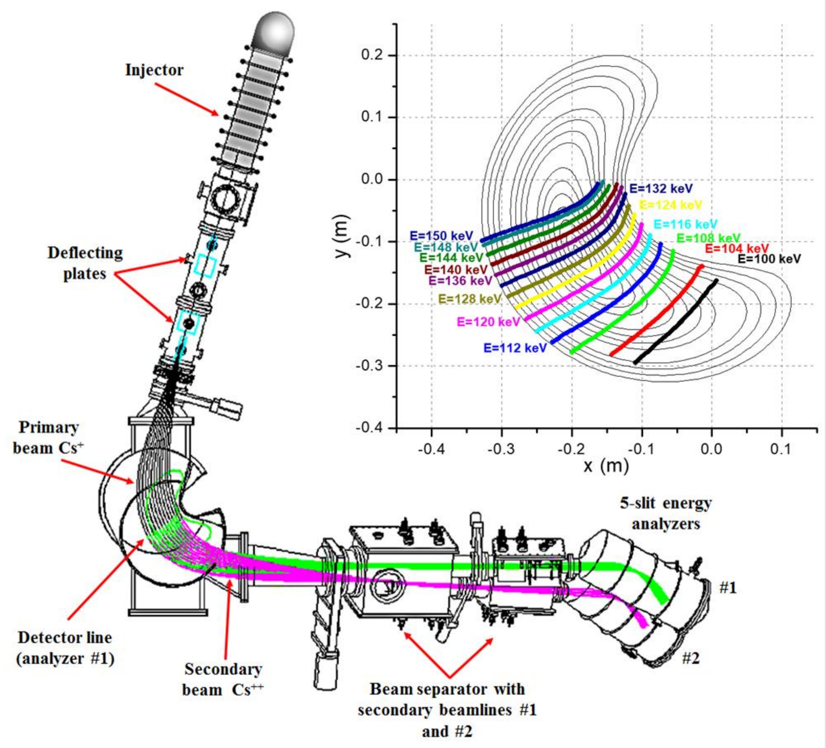
Experimental setup

TJ-II stellarator

R = 1.5 m, ***a*** = 0.22 m, **B_0** = 0.95 T
ECRH (two 53.2 GHz ≤300 kW gyrotrons)
NBI (two 600 kW H_2 injectors, E=40 keV)

HIBP

- **Cs^+ ions** with energies E_b up to **150 keV**
- Probing beam current up to **250 μA**
- 5-slit energy analyzer:
- Full radial scan from LFS(**ρ=1**) to HFS (**ρ= -1**) in 5-20 ms at E_b = 132 keV



Studied regimes:

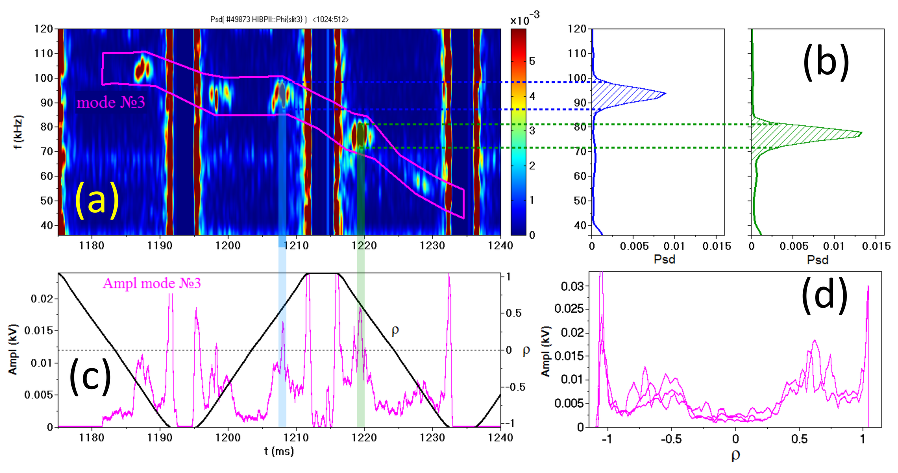
1 (low $\bar{n}_e$): ECRH_1+2 (470 kW), $\bar{n}_e$ = 0.5±0.07 x10^{19}m^{-3}, T_e^0= 1.6 keV
2 (high $\bar{n}_e$): ECRH_1 (250 kW), $\bar{n}_e$ = 0.7± 0.1 x10^{19} m^{-3}, T_e^0 = 1.3 keV
3 (NBI) : co-NBI (510kW), n_e = 0.9 ÷ 1.3 x10^{19} m^{-3}, T_e^0 = 0.6 keV

Fluctuation processing

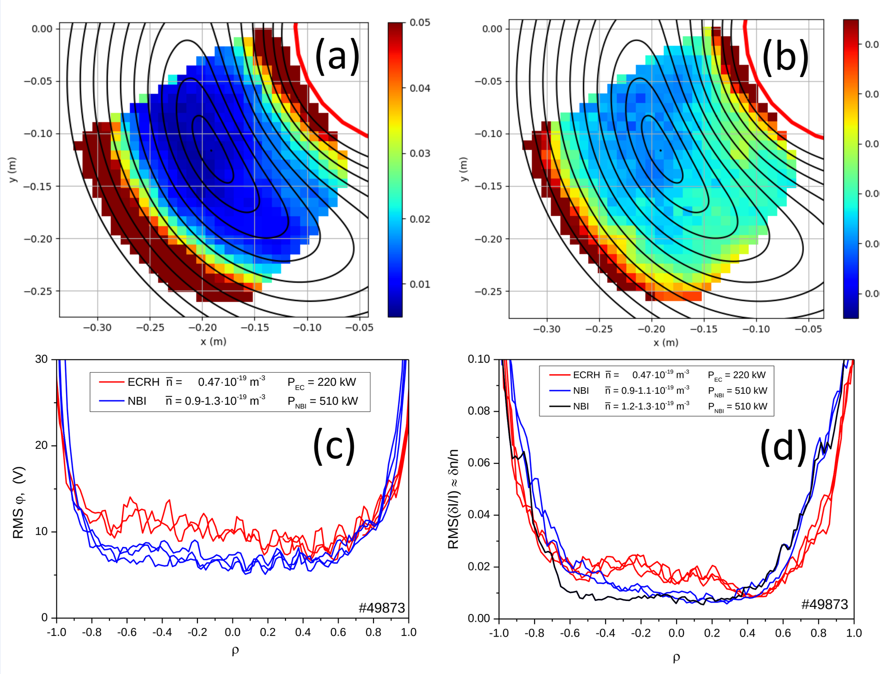
2D distributions of fluctuations were obtained using integration of PSD spectrogram in a spectral band.
From Parseval theorem we can estimate the RMS in the arbitrary spectral band as

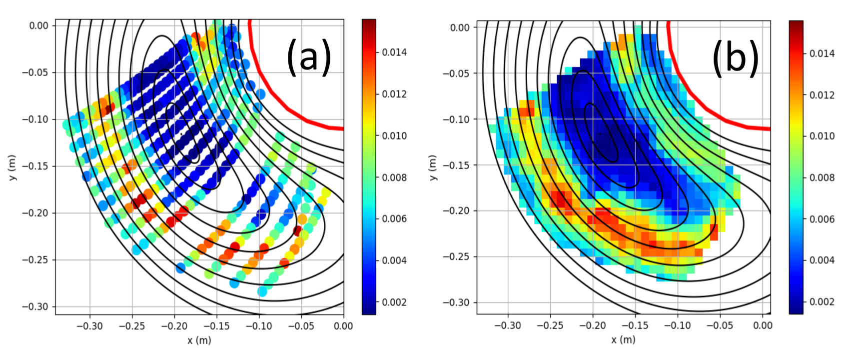
$$RMS^{band}(t) = \sqrt{\frac{1}{f_{Nyq}} \int_{f_{min}(t)}^{f_{max}(t)} S(f,t)\, df}$$

where $S(f,t)$ is PSD of studied signal, fNyq is Nyqvist frequensy and [$f_{min}(t)$, $f_{max}(t)$] is spectral band.
The same method can be applied for the broad-band turbulence (multiband case).



(a) Spectrogram of the plasma potential with selected AE mode, (b) time slices of the spectrogram, (c) temporal evolution of the AE amplitude (=√2·RMS)
(d) Radial profile of the AE amplitude





2D distribution of the amplitude of the AE measured shot-by-shot energy scan: (a) amplitudes along detector lines (averaged by shot) , (b) 2D interpolation.

2D distribution of the broad-band RMS (a) for plasma potential (b) for $\frac{\tilde{I}_{tot}}{I_{tot}} \approx \frac{\tilde{n}_e}{n_e}$ and comparison of the broad-band RMS in ECRH and NBI regimes for (c) plasma potential and (d) beam current $\frac{\tilde{I}_{tot}}{I_{tot}}$

ACKNOWLEDGEMENTS / REFERENCES

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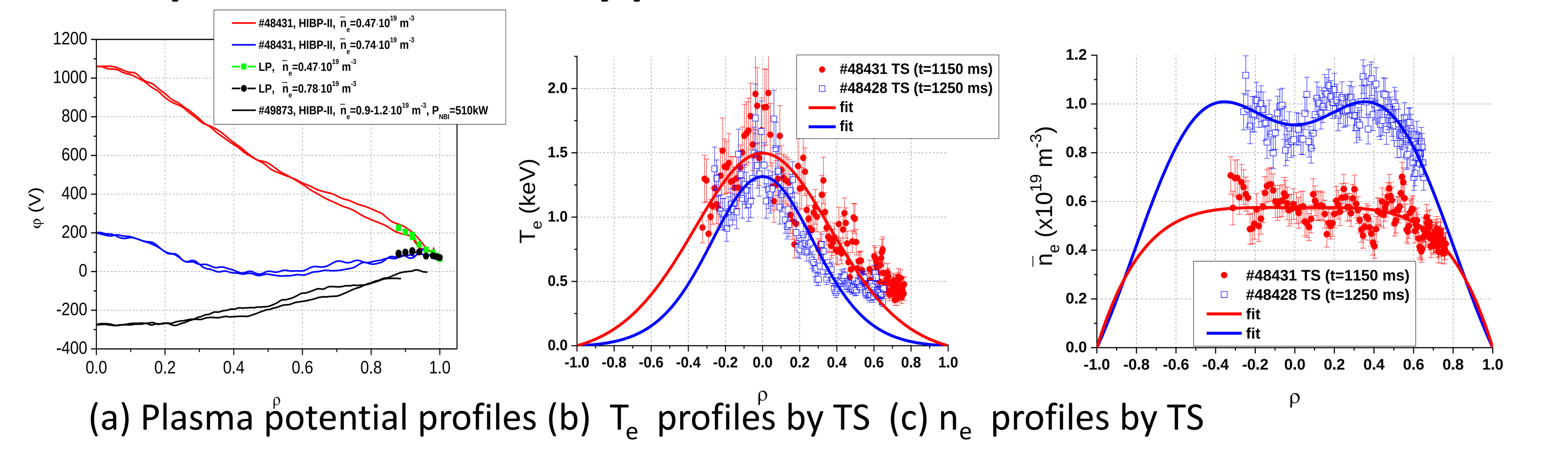
OUTCOME

Plasma potential and density profiles evolution

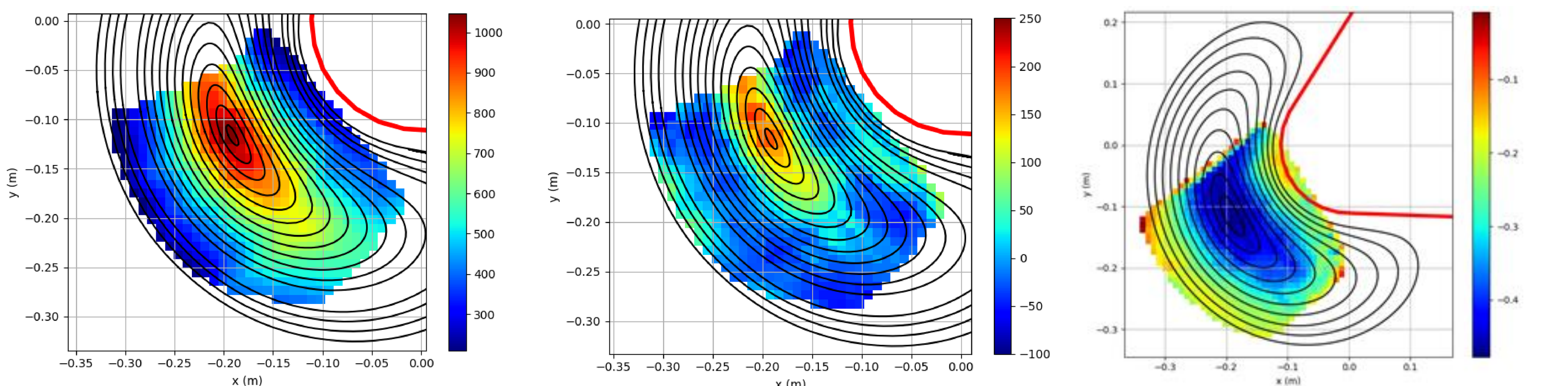


(a) Plasma potential profiles (b) T_e profiles by TS (c) n_e profiles by TS

2D distribution of plasma potential

Potential contour plot covers about one half of the plasma poloidal cross-section:

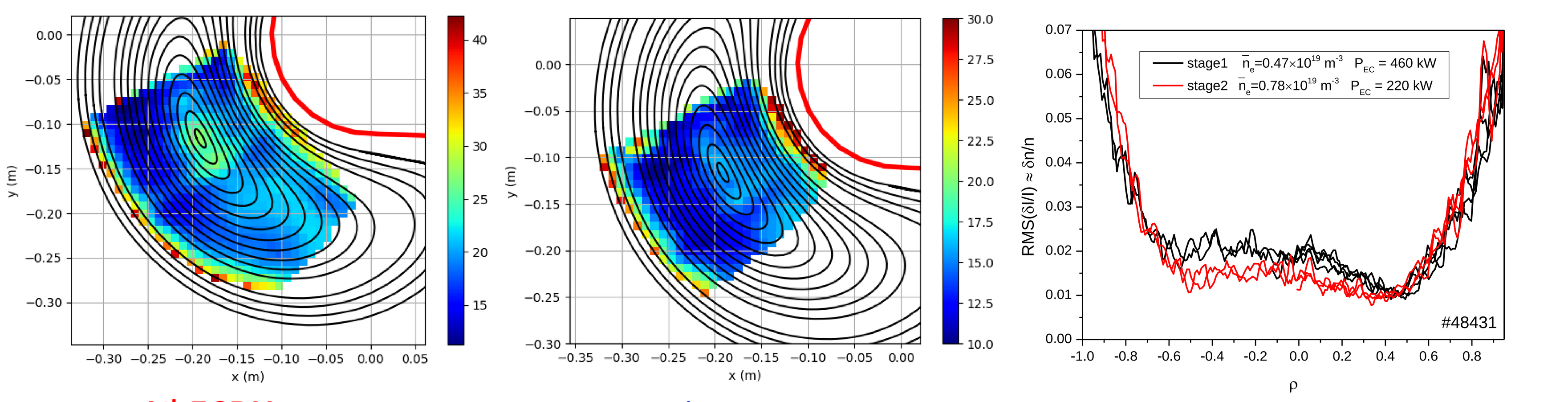
- the maximum of 2D potential distribution (**~ 1000 V; ~ 200 V**) is located at the magnetic axis
- equipotentials are **consistent** with vacuum magnetic flux surfaces
- 2D potential distribution is **symmetric** (LFS-HFS and up-down)



1st ECRH stage — 2nd ECRH stage — NBI phase

2D distribution of plasma potential fluctuations

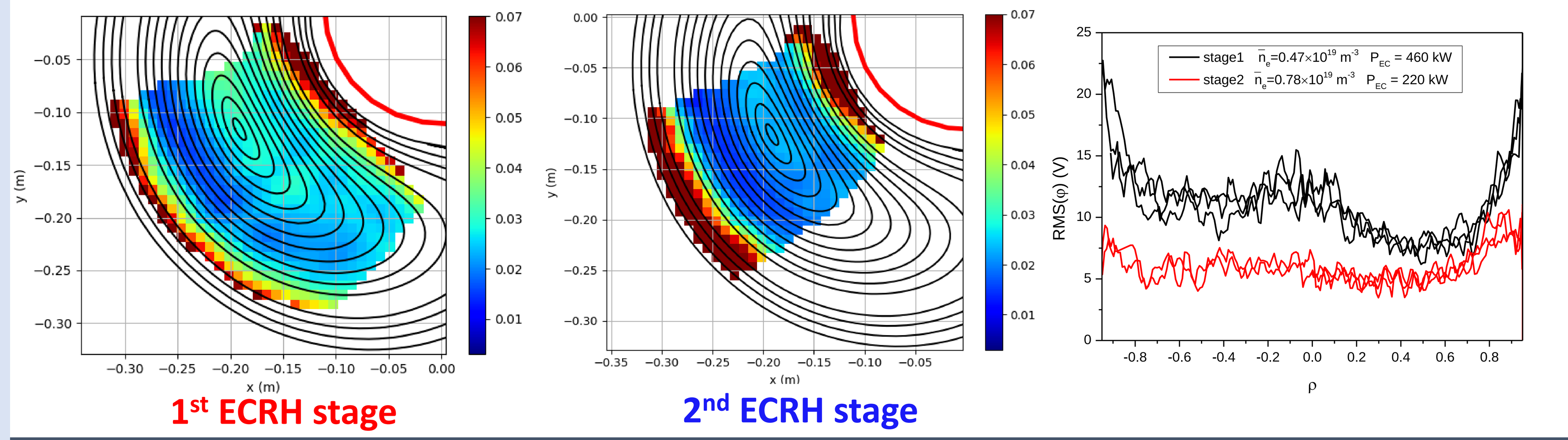
- the maximum of 2D RMS distribution is located at the magnetic axis (**~ 30 V, ~ 15 V**) and at the edge (**~ 40 V, ~ 30 V**)
- equipotentials are basically consistent with vacuum magnetic flux surfaces
- 2D distribution is not fully symmetric:
  at the mid-radius **~ 15 V, ~ 12 V (LFS)** vs **~ 20 V, ~ 15 V (HFS)**



1st ECRH stage — 2nd ECRH stage

2D distribution of plasma density fluctuations

- the density perturbation has a local maximum at the centre (**~ 3%, ~ 2.5%**) and maxima at the edges (LFS and HFS) up to **7%** and **15%**
- the level of the density perturbation is asymmetric, it is lower in LFS (**~ 2%, ~ 1.5%**) in contrast to HFS (**~ 3%, ~ 2%**) near mid radius - area of the maximum density



1st ECRH stage — 2nd ECRH stage

SUMMARY

- 2D plasma potential distribution was measured in the ECRH plasmas of TJ-II for the first time in a wide area of vertical cross-section in ECRH and NBI plasmas.
- In both ECRH and NBI plasmas equipotential lines are consistent with vacuum magnetic flux surfaces, 2D potential distribution is symmetric (LFS-HFS and up-down) with local extrema at the plasma centre.
- In low-density (ne=0.5-0.8·10^{19}m^{-3}) ECRH plasmas potential and density RMS are not fully symmetric, the effect is stronger for lower-density case: at the mid radius (area of the maximum density) broadband turbulence RMSφ ~ 15 V at LFS versus ~ 20 V at HFS, RMS ne ~ 2% at LFS versus ~ 3% at HFS. In the NBI plasmas with the density raise the asymmetry is decreasing and finally vanishing at ne=1.2-1.3·10^{19}m^{-3}.
- 2D distribution of the NBI-induced Alfven eigenmodes show asymmetric structures: contrary to broadband turbulence AE-associated potential perturbation dominate in the LFS with a factor up to 1.7 respect to the HFS.