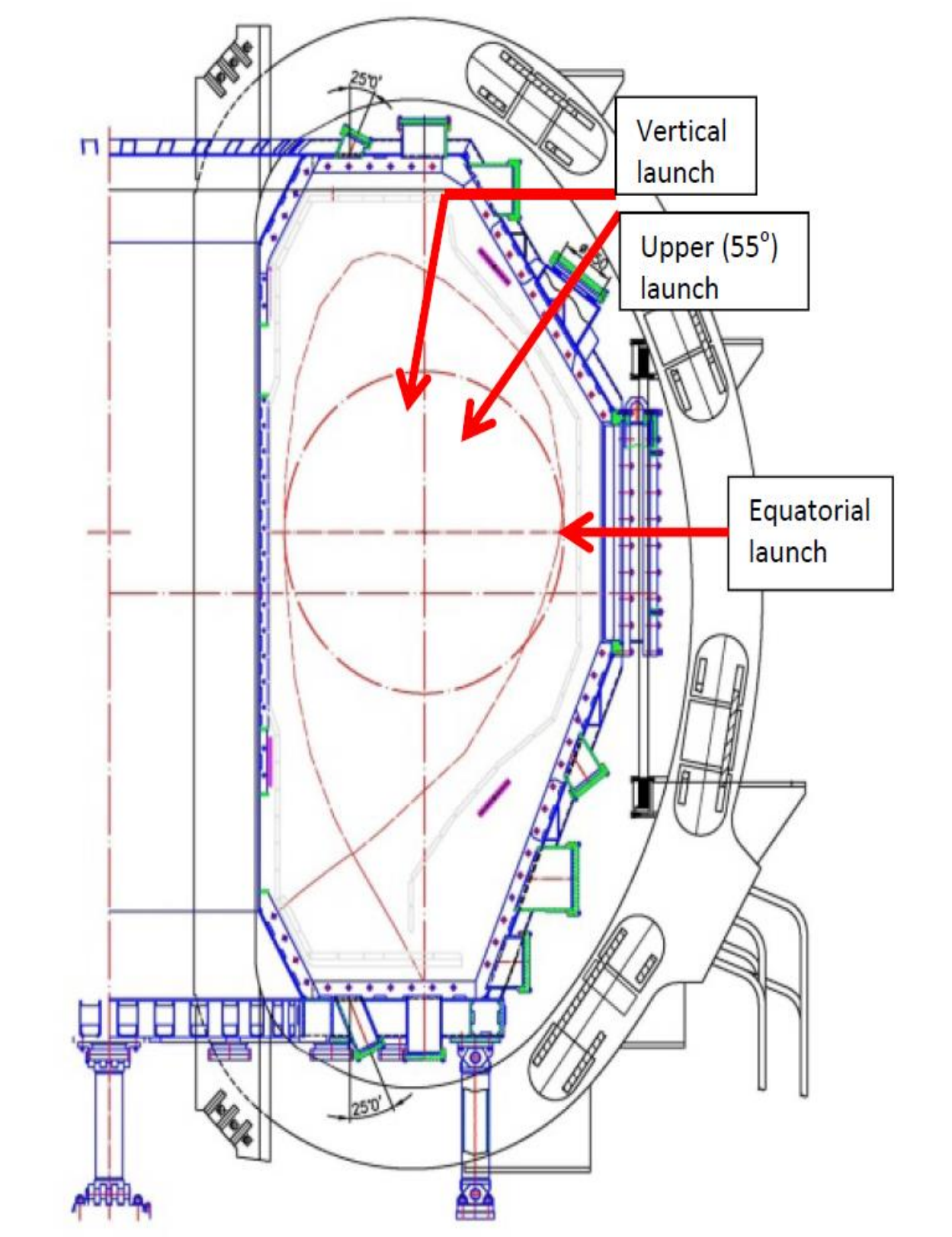
TH-P8/24

Modelling of ECRH/ECCD at Different Power Launch Geometry in T-15MD Tokamak

N.A. Kirneva [1,2], A.A.Borschegovskii[1], D.A.Kislov[1], A.Yu.Kuyanov[1], I.S.Pimenov[1], I.N.Roy[1]
[1]NRC “Kurchatov Institute”, Moscow, Russia [2]NRNU MEPhI, Moscow, Russia
Kirneva_NA@nrcki.ru

T-15MD PARAMETERS



T-15MD project parameters [1]:
Major raius R_0=1.48 m
Plasma minor radius a=0.67 m
Elongation k=1.8
Triangularity δ=0.4
Aspect ratio A=2.2
Plasma current I_p=2 MA
Toroidal magnetic field B_T=2 T
Configuration SN/DN
Working gas H
Pulse duration up to 30 s
Heating
- ECRH/ECCD 8 gyrotrons x 1MW
- LHCD 4 MW
- ICRH 6 MW
- NBI 8-10 MW

FIG. 1. T-15 MD cross-section and schematic view of the possible EC wave launchers

PARAMETERS OF THE ECRH/ECCD SYSTEM

- Launchers are planned to be installed in 2 toroidal cross-sections
- Three ports – equatorial, inclined upper 55°, vertical - are considered (FIG. 1)
- Steerable mirrors will be installed to change toroidal and poloidal injection angles

Scheme	Launcher	$R_{launcher}$, cm	$Z_{launcher}$, cm
Equatorial	Pure Equ.	240	0
	Equ.1	254.2	12
	Equ.2	257.5	33.4
Upper (55°)	Upper (55°)	208.7	84
Vertical	Vertical	169.6	141.8

- 1 gyrotron (1 MW, f=82.6 GHz) will be installed in Equatorial launcher at the beginning of the T-15MD operation for the breakdown assistance

Goal of this paper: modelling of the power and current profiles from one gyrotron (1MW, 82.6 GHz) for various launch geometry to provide a background for further development of ECRH complex of T-15MD Tokamak.

MODELLING CONDITIONS

ASTRA [2]: Initial T_e and n_e distributions

OGRAY [3]: modeling of EC power absorption and ECCD

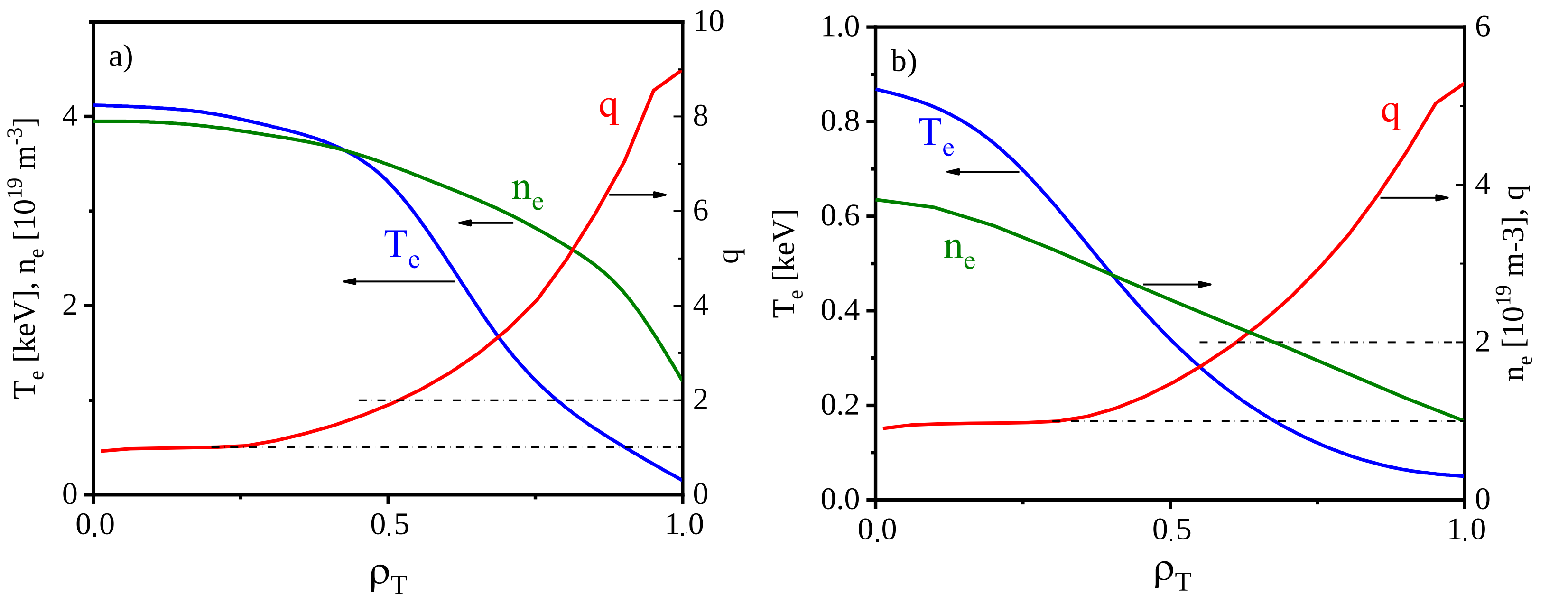


FIG. 2 T_e, n_e and q profiles for background Regimes 1 [4] (a) and 2 (b)

Regime	k	δ	q_L	z_{eff}
1. Powerful heating	1.75	0.35	9.5	1.6
2. Ohmic regime	1.3	0.2	5.2	2.5

EC beam parameters:
Half width at e^{-1} level D_w=3.6 cm
Wave front curvature radius R_w=234 cm

FREQUENCY OF THE FIRST GYROTRON

X2: higher cut-off density than for O1
f=82.6 GHz in order to have EC resonance inside of vacuum vessel in a wide range of B_T values

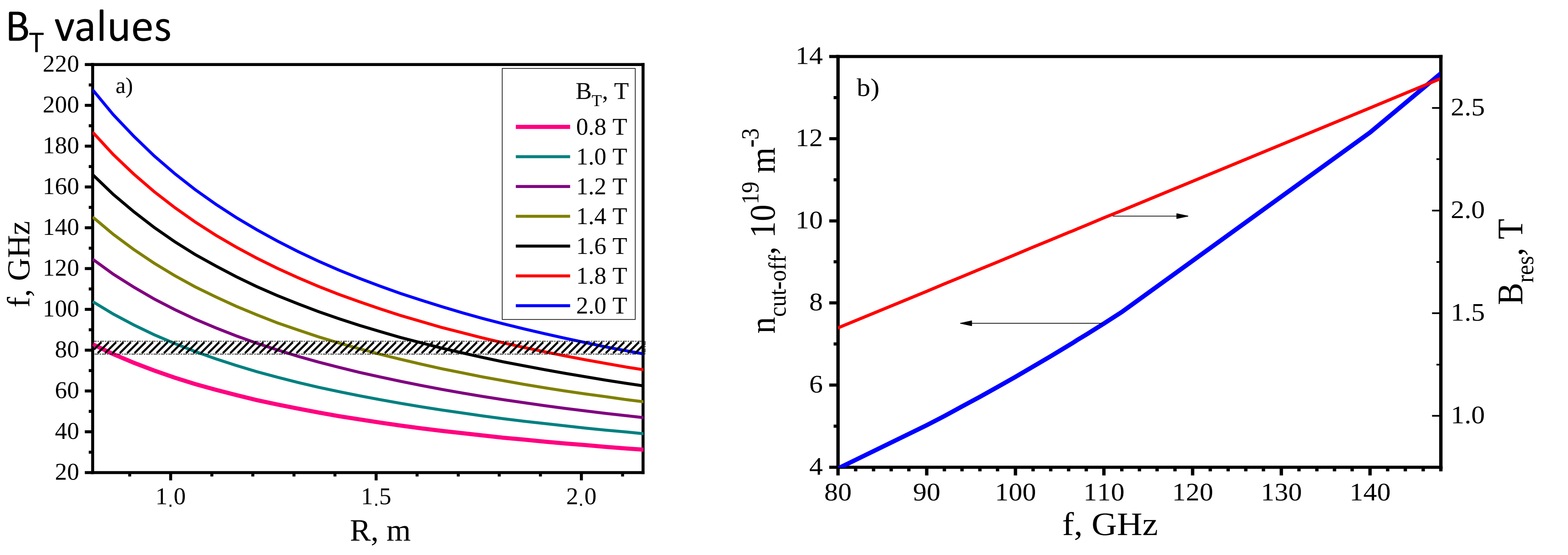


FIG. 3. (a) X2 resonance position inside of T-15MD vacuum vessel for different B_T value; (b) the cut-off density and resonant magnetic field value for X2 EC wave in a reasonable frequency range for T-15MD

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EFFECT OF THE REFRACTION

X2, f=82.6 GHz: $n_{cut-off}$=4.2x10^{19} m^{-3}

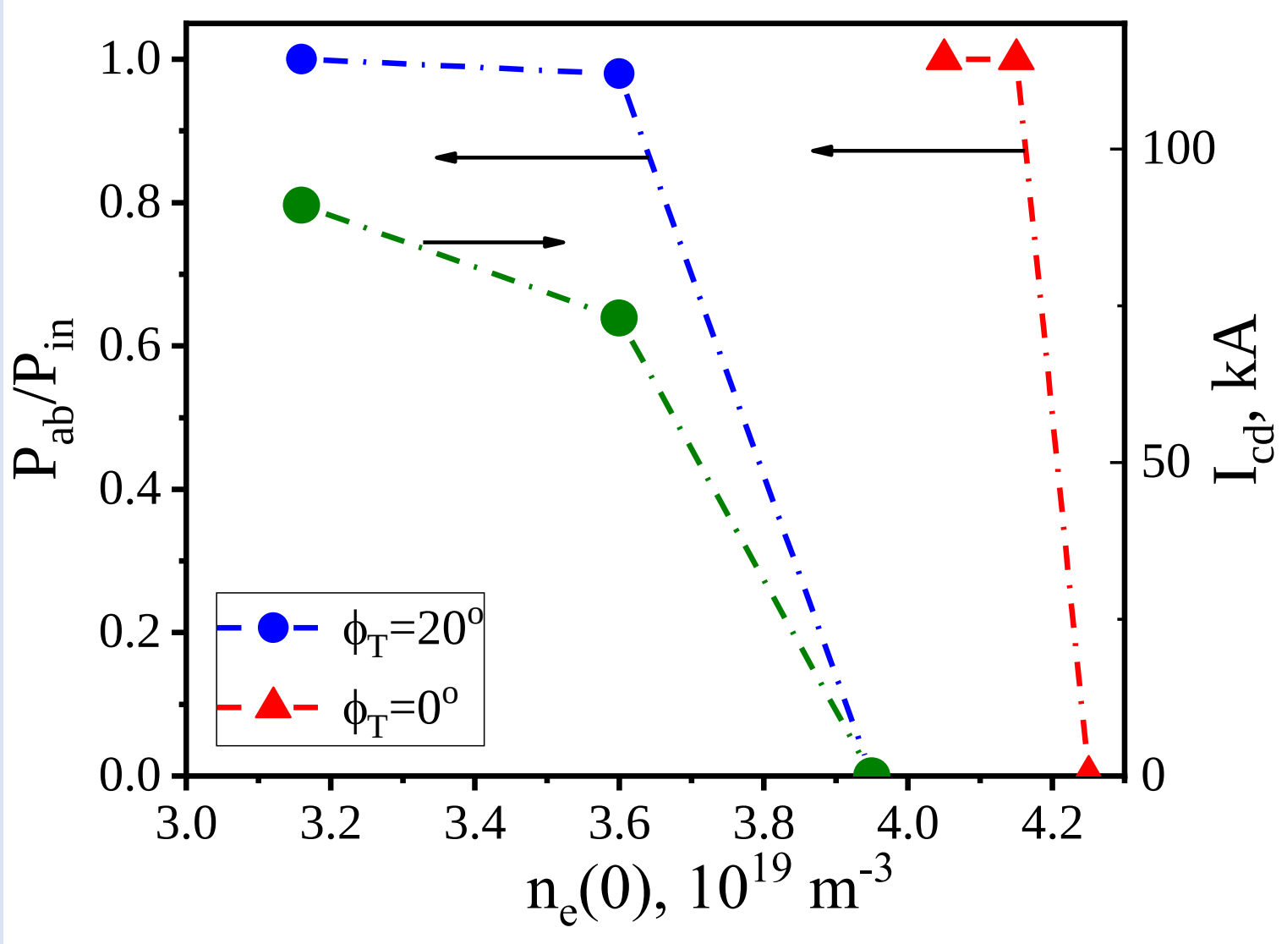

FIG. 4 Dependence of the absorbed power and driven current for ϕ_T=20° and ϕ_T=0° on plasma density. Pure equatorial launch, on-axis ECCD.

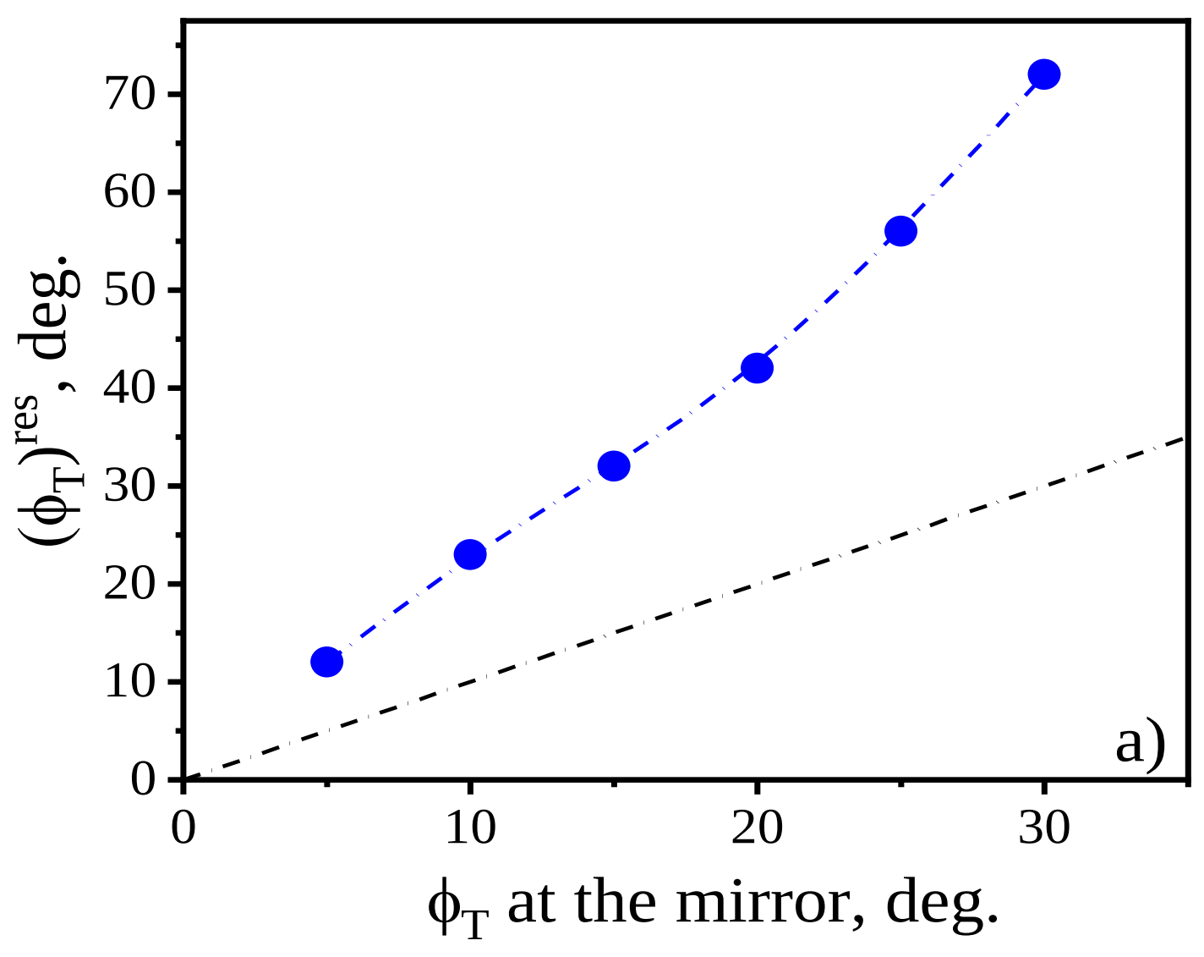

FIG. 5. Dependence of the toroidal angle at the resonance position on toroidal launch angle for the pure equatorial launch and on-axis absorption.

ECRH/ECCD by X2 EC wave with f=82.6 GHz is possible only in low density T-15MD plasmas. Higher frequencies (102-112 GHz and 140 GHz) and another modes of operation (X3) are discussed for the next step gyrotrons [5-7].

SCAN OF POLOIDAL LAUNCH ANGLE

ϕ_p variation in the range of ϕ_p=-5°…+30° provides the variation of EC power deposition from on-axis to off-axis (ρ~0.6) in Regime 1 in case of equatorial power launch. EC beam injection through the upper (55°) port will extend the range of heating positions to ρ~0.8 that can be important for the regimes with H-mode.

ECCD AT DIFFERENT LAUNCHING SCHEMES

n_e(0)=2.5x10^{19} m^{-3}

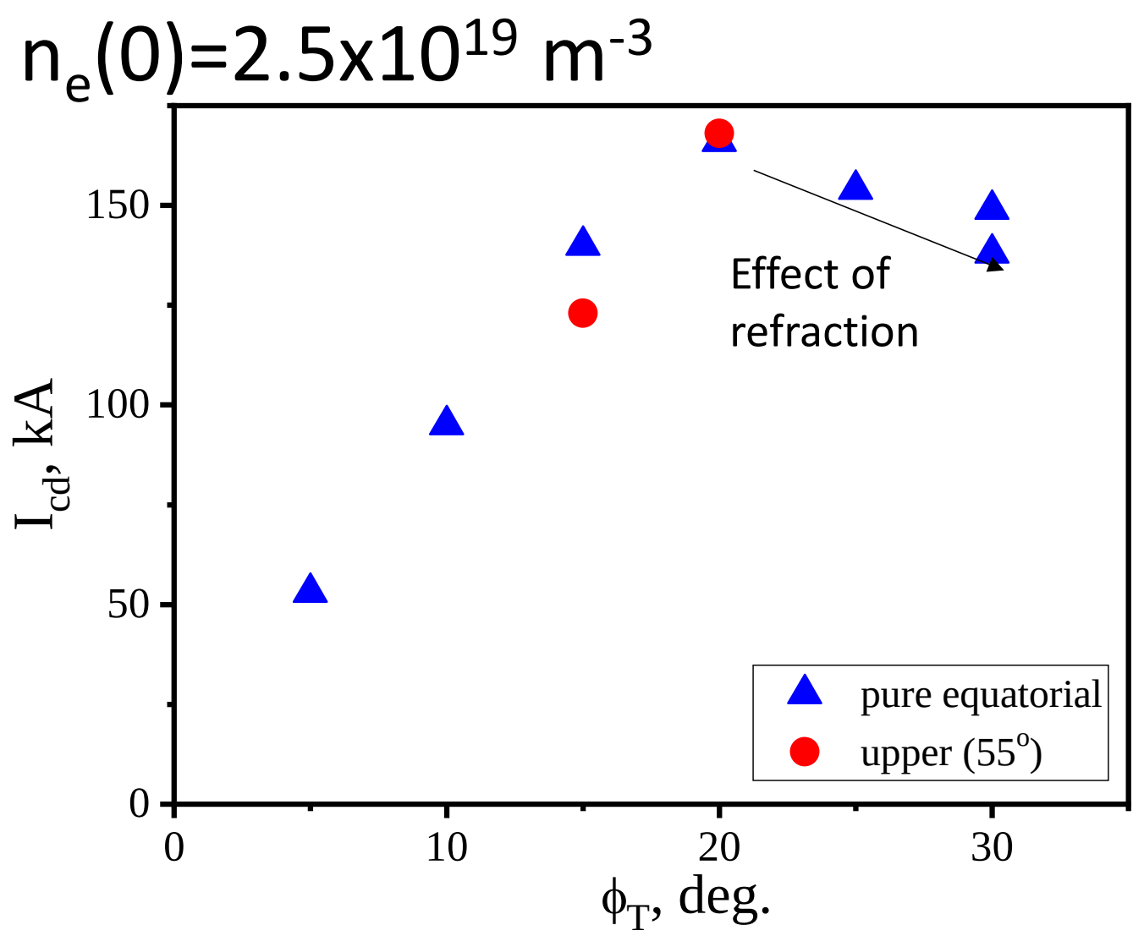

FIG. 6. Dependence of the EC current on toroidal launch angle.

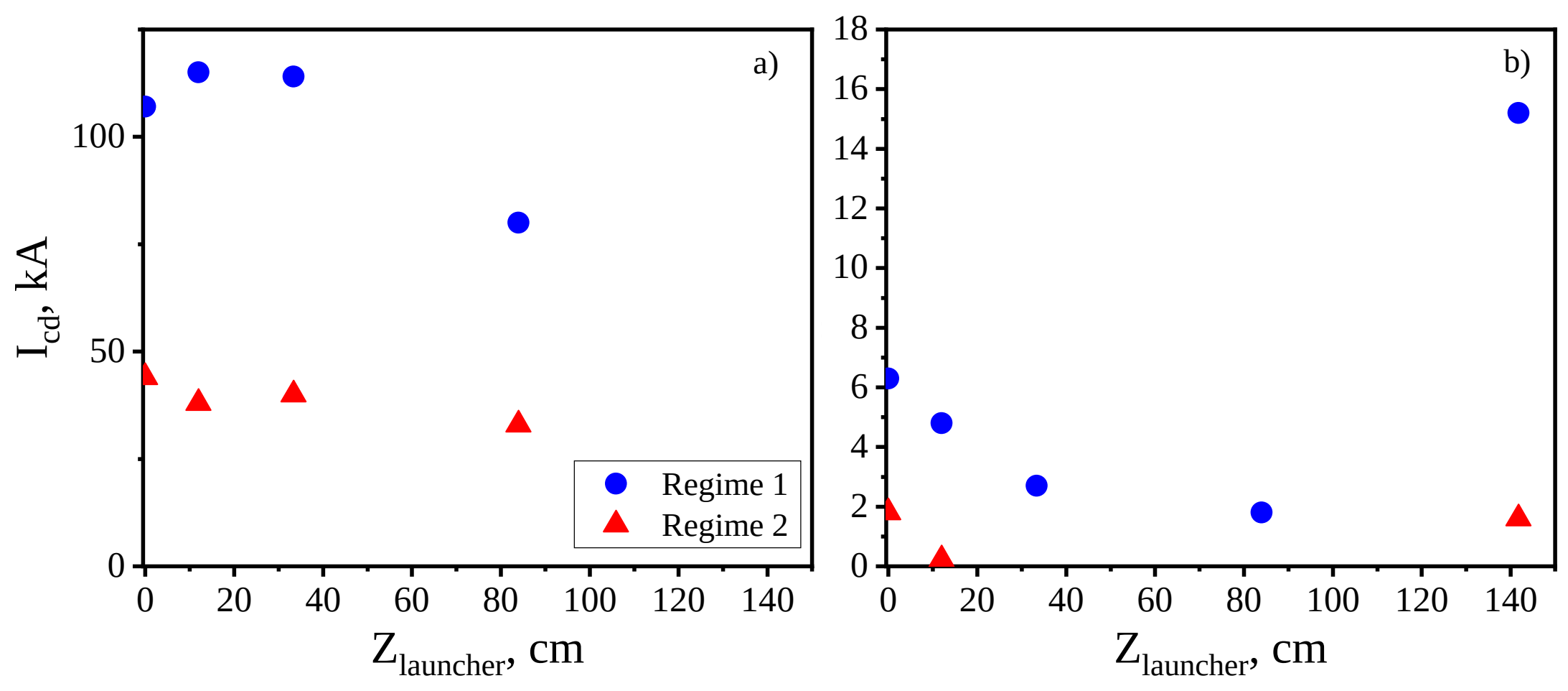

FIG. 7. EC current value for different launch schemes in case of (a) on-axis and (b) off-axis (ρ~0.45 above magnetic axis) current drive. ϕ_T=15°.

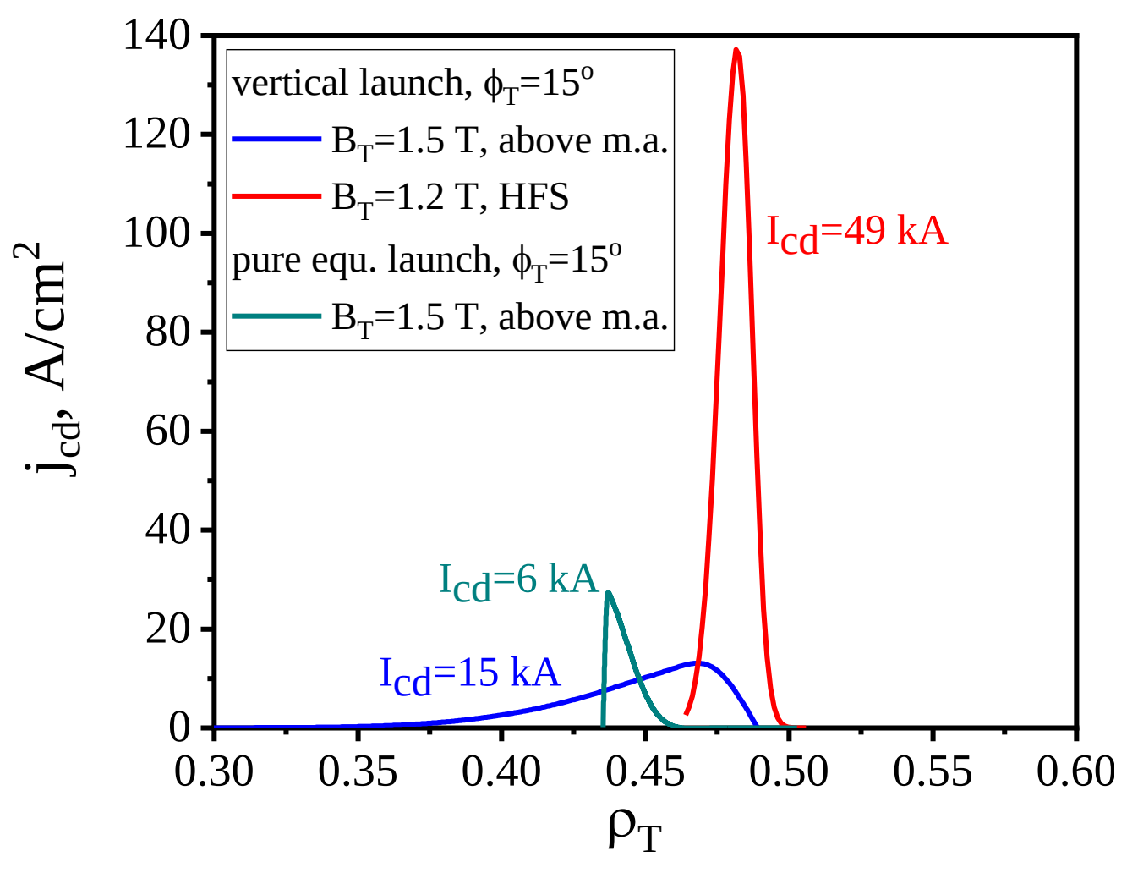

FIG. 8. EC current profiles for off-axis ECCD for different launch schemes.

1. On-axis ECCD:
   - η~0.5x10^{19} A/W/m² for high power high shaping plasmas
   - η~0.17x10^{19} A/W/m² for OH background regime with low k and δ

   Difference is caused by the T_e and z_{eff} difference.
2. Off-axis ECCD: I_{cd} decrease seems to be caused
   - mainly by the trapped particle effect in Regime 1
   - trapped particle effect and peaked temperature profile in Regime 2
3. Off-axis ECCD on HFS seems to be more efficient. It does not contradict to the trapped particles effect.

EFFECT OF 3RD ECR HARMONIC

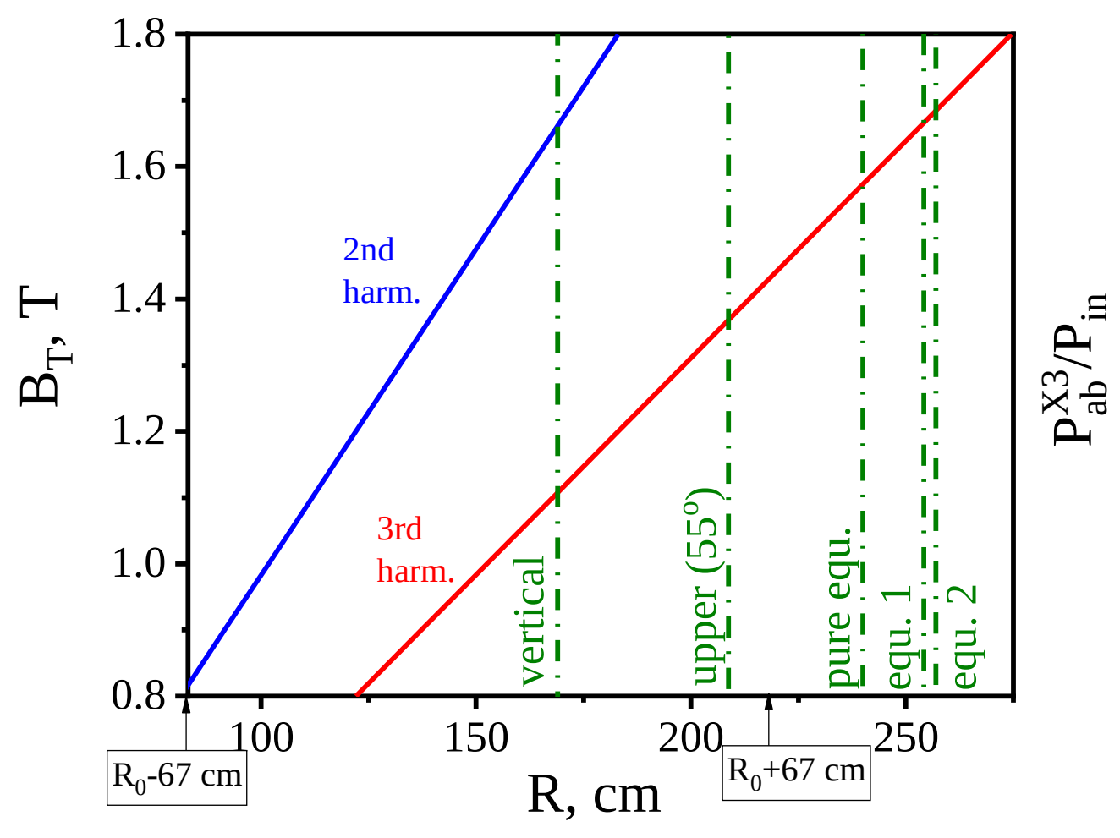

FIG. 9. Cold resonance positions for 2nd and 3rd ECR harmonics (f=82.6 GHz) relatively to the last mirror position

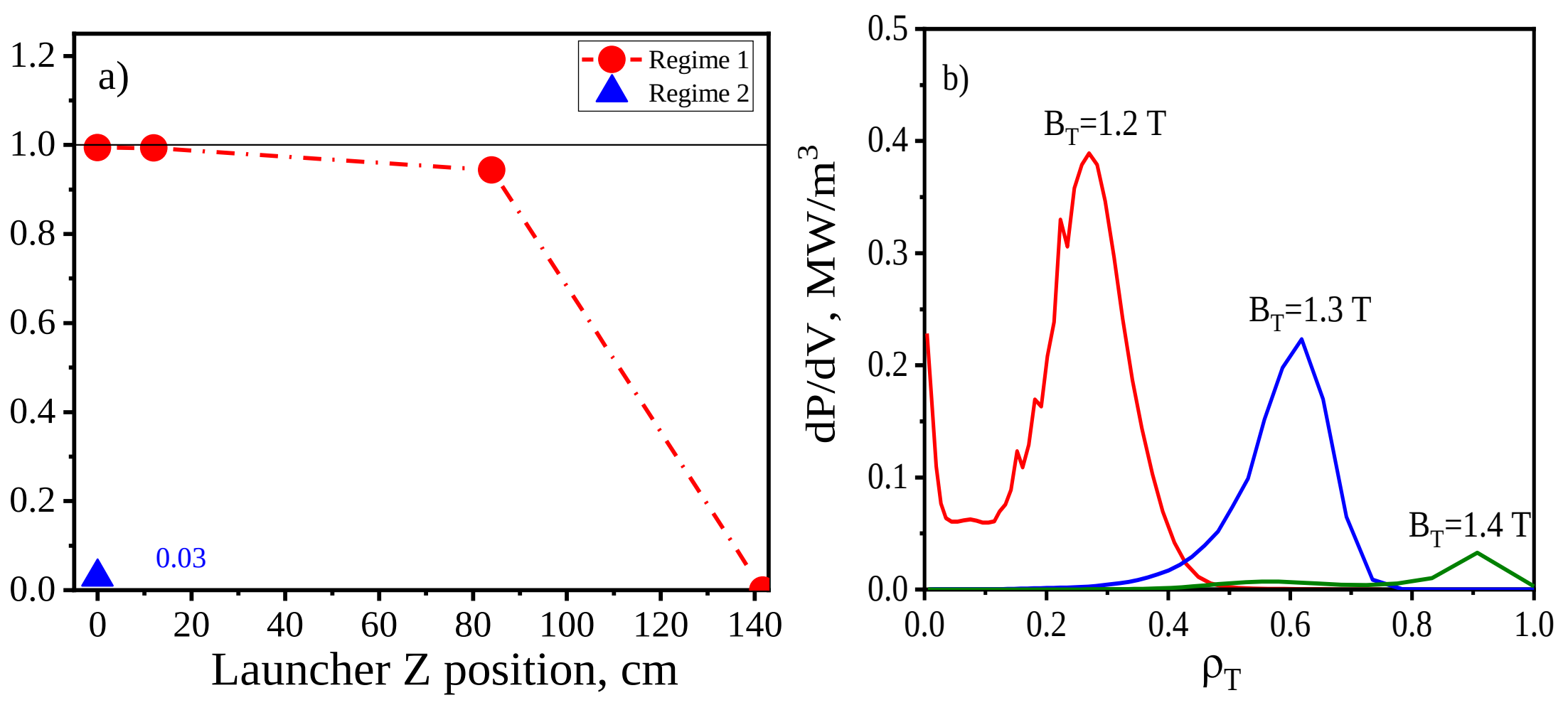

FIG. 10. Dependence of the power absorbed in X3 layer on B_T value (a) for different launch geometry in high power operation (Regime 1) and X3 absorbed power profiles for different magnetic field values for pure equatorial launch(b). φ_T=20°.

Due to the X3 absorption, ECRH/ECCD on HFS by X2 wave can be sufficiently reduced for equatorial and upper 55° launchers. Heating and current drive using the X2 wave at the HFS in regime with high temperature becomes efficient only for the vertical launcher (FIG. 8). In low temperature, low shaping regime the X3 absorption is negligible.

CONCLUSIONS

- The first gyrotron frequency was chosen as f=82.6 GHz to provide X2 resonance inside of the vacuum vessel in a wide range of B_T values on the initial phase of the operation. Application of this frequency is limited by the low density discharges due to the effect of the refraction. Gyrotrons with higher frequencies are required in order to extend the operational density range for ECCD/ECRH.
- EC wave injection using equatorial, upper (55°) and vertical launchers provides a wide range of power and EC current deposition locations from on-axis to far off-axis.
- ECCD calculations demonstrated the increase of the driven current with φ_T up to φ_T=20°. Further increase of φ_T does not lead to the I_{cd} increase presumably due to the enhanced refraction. Strong difference between the toroidal angle at the resonance and φ_T at launcher due to the low aspect ratio of the machine should be taken into account.
- Coexistence of X3 and X2 resonances in the plasma can be obtained at some range of magnetic fields. Vertical power launch is useful to avoid parasitic absorption on X3 resonance and to get high off-axis current drive efficiency by X2 wave on HFS.