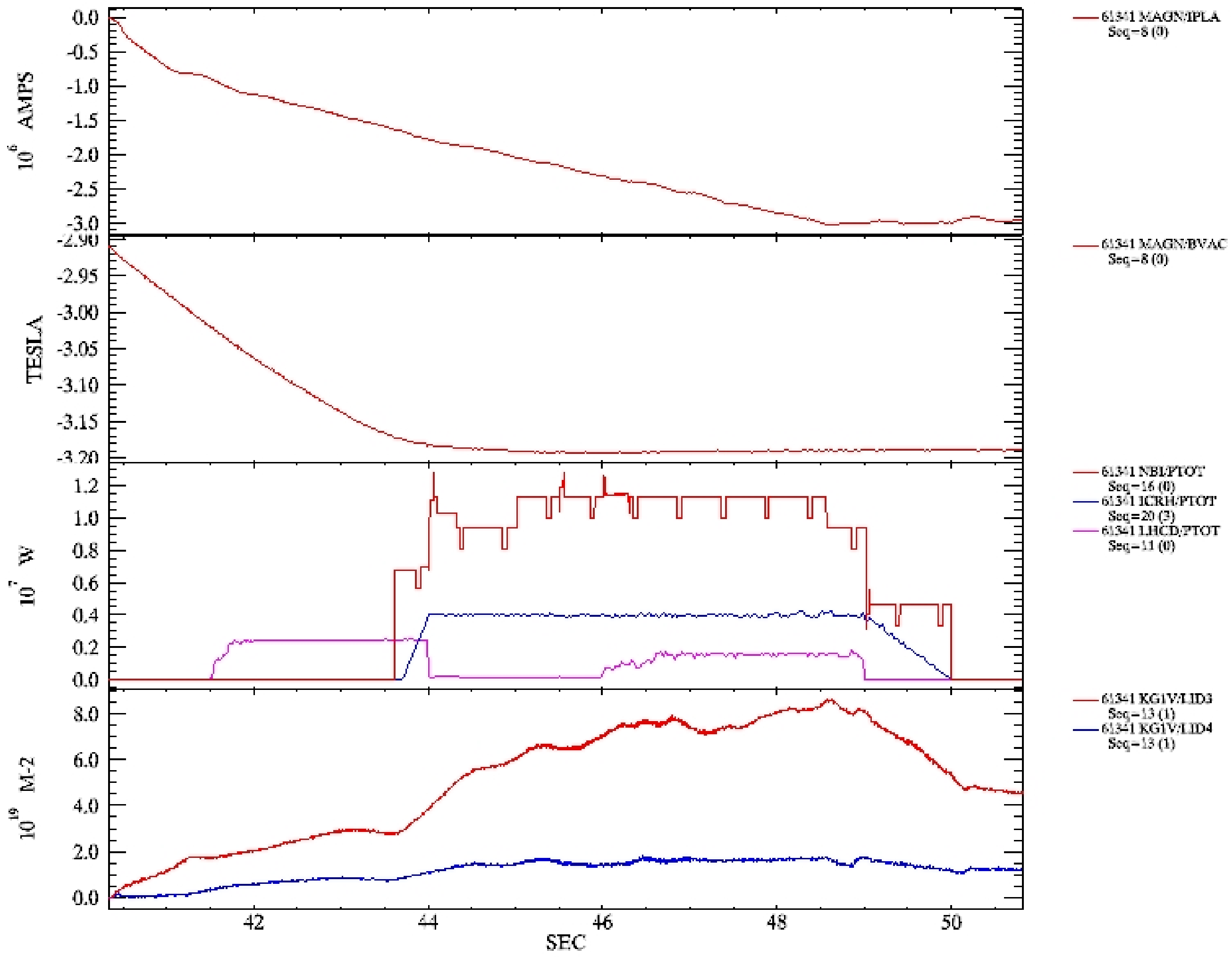
On the relation between EC emission and LHCD power spectrum in the plasma. LH psectrum modification due to density fluctuations.

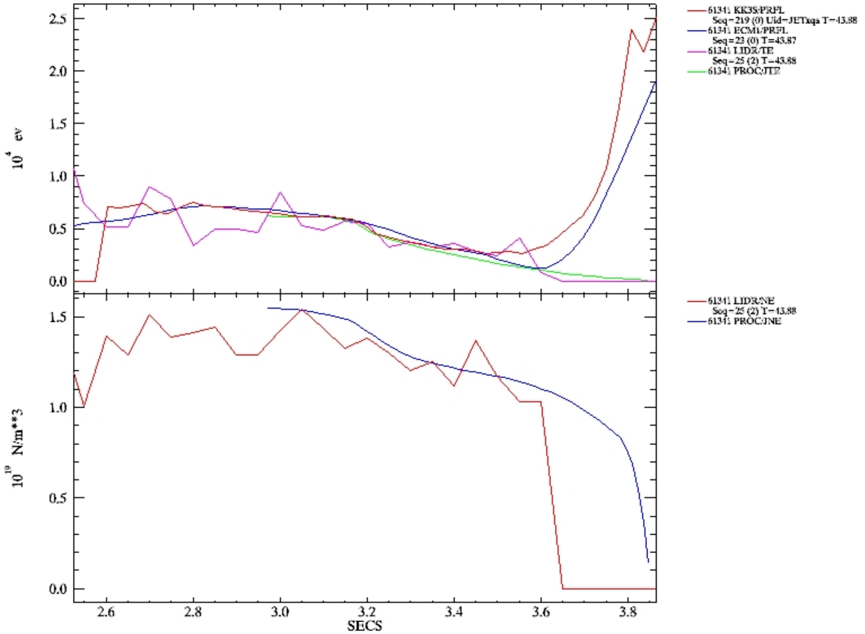
(Preliminary results)

Yu.F.Baranov

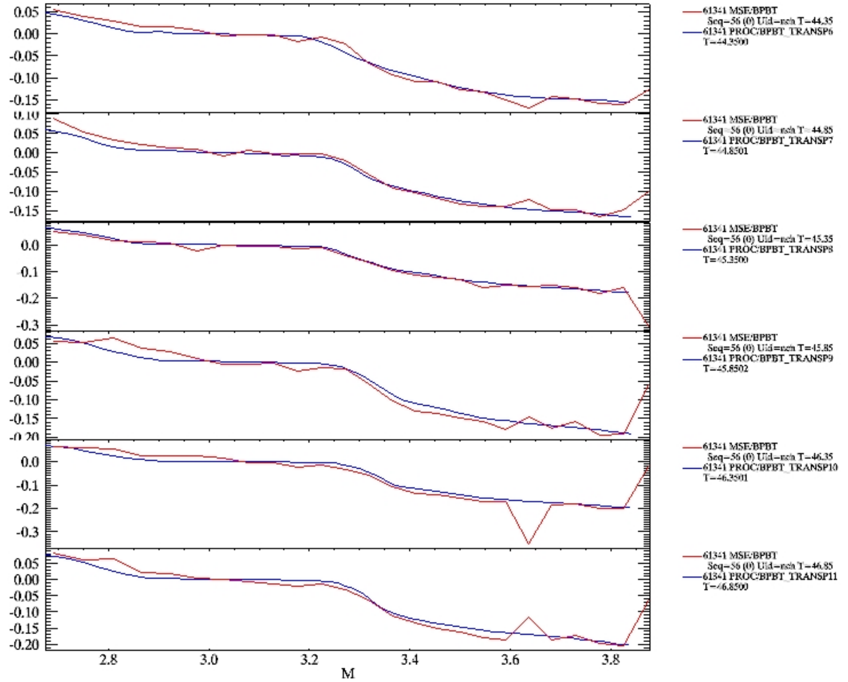
Motivation: Electron cyclotron emission (ECE) is sensitive to the supra thermal electrons produced by LHCD. Modelling of the ECE and comparison with the measured signal can be useful for the diagnostic of the electron distribution function, which is directly related to the LH power spectrum inside plasma. LH spectrum modification due to density fluctuations is being investigated. Validity of T_e measurements in the presence of LH waves can be assessed.



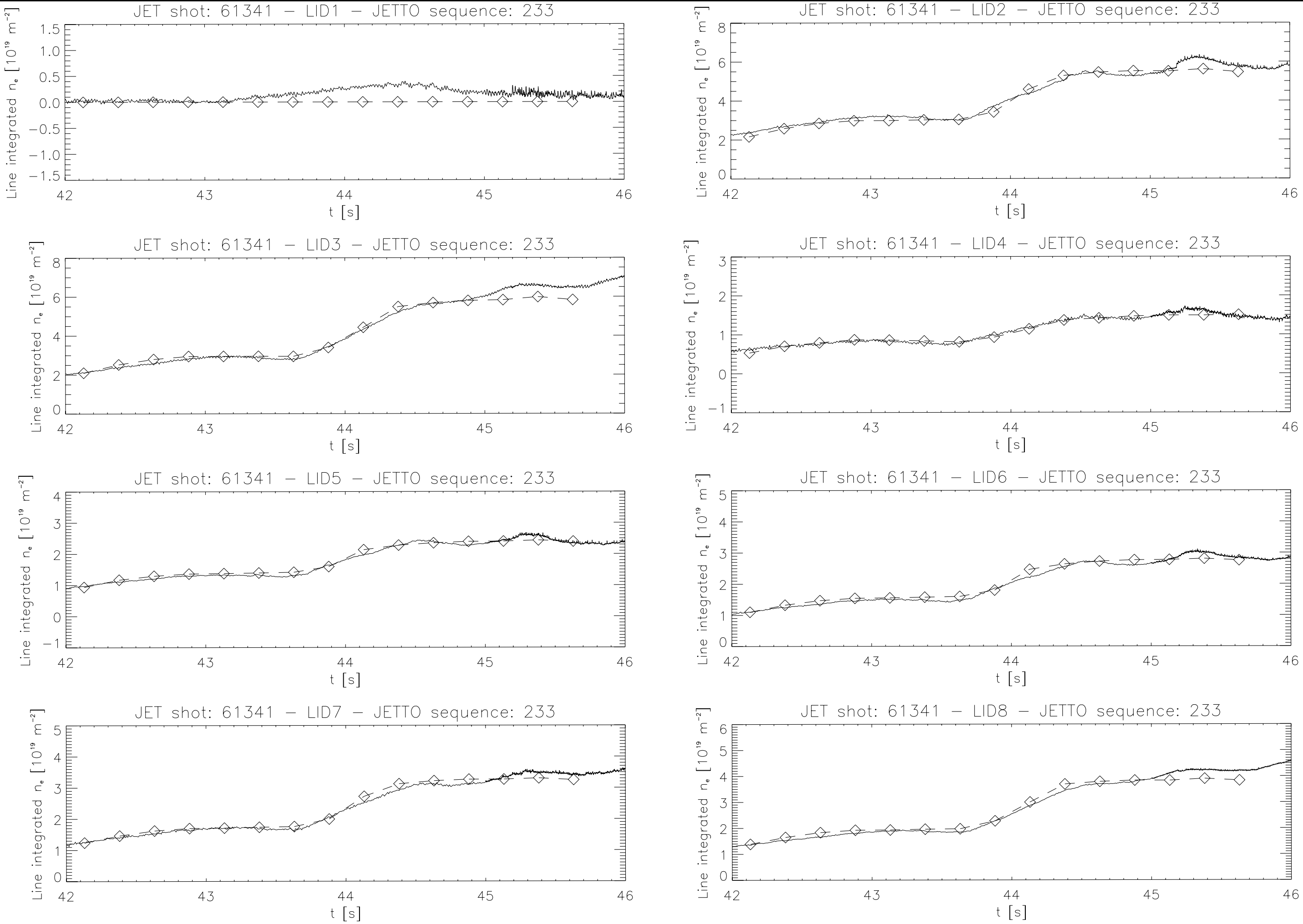
Evolution of the main plasma parameters. #61341.



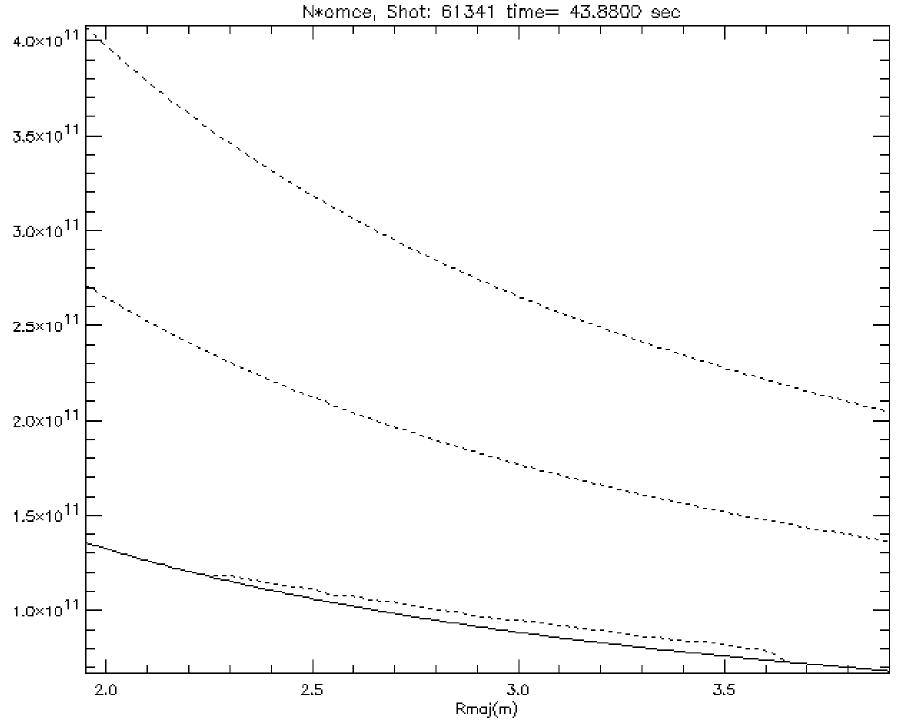
T_e and N_e from LIDR, ECM1, KK3, t=43.88s, #61341



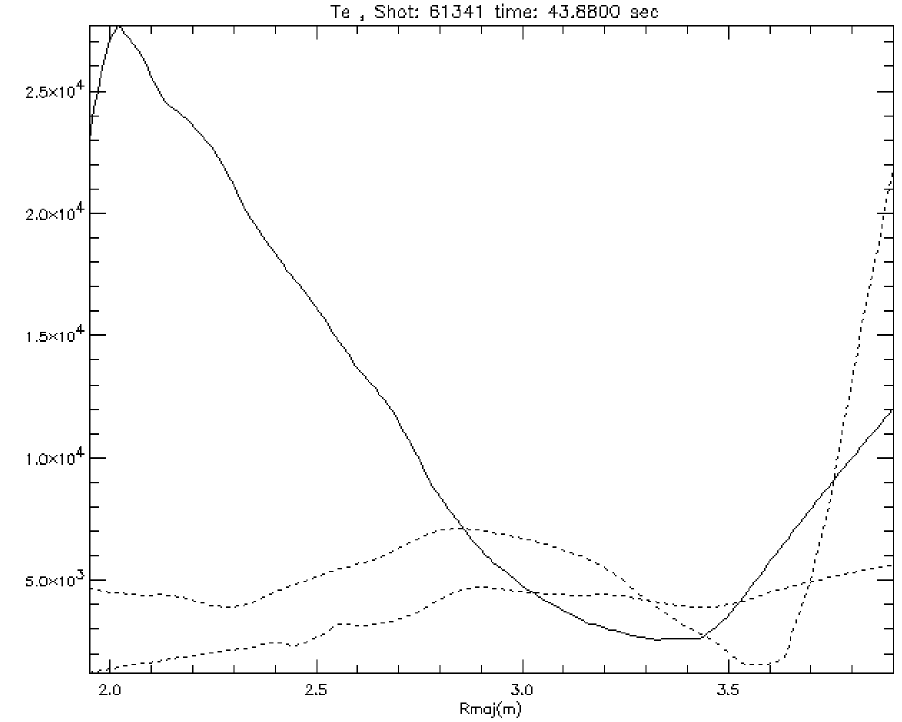
q-profile modelling is verified by comparison of calculated and measured by MSE pitch angle.



density profiles are reconstructed in agreement with interferometer measurements



EC emission frequency
Solid line-first harmonic
Dotted line-second harmonic
Dashed line-third harmonic
#61341, t=43.88s



Radiation T_e in discharge with LHCD
Solid line-first harmonic
Dotted line-second harmonic
Dashed line-third harmonic,
#61341, t=43.88s

Modelling of ECE during LHCD

1. LHCD modelling includes:

a) Ray tracing calculations-solution of the Hamiltonian equetions

$$\frac{d\rho}{dt} = -\frac{\partial D/\partial k_\rho}{\partial D/\partial \omega} \qquad \frac{d\theta}{dt} = -\frac{\partial D/\partial k_\theta}{\partial D/\partial \omega} \qquad \frac{d\zeta}{dt} = -\frac{\partial D/\partial k_\zeta}{\partial D/\partial \omega}$$

$$\frac{dk_\rho}{dt} = \frac{\partial D/\partial \rho}{\partial D/\partial \omega} \qquad \frac{dk_\theta}{dt} = \frac{\partial D/\partial \theta}{\partial D/\partial \omega} \qquad \frac{dk_\zeta}{dt} = \frac{\partial D/\partial \zeta}{\partial D/\partial \omega}$$

1.1.1 **b) SCATTERING OF THE LOWER HYBRID WAVES**

Scattering of the slow LH waves by low frequency density fluctuations is taken into account using a theory proposed by Ott. The spectrum of fluctuations is approximated by a Gaussian function

$S(k)=(1/\pi k_o^2)\langle \delta n/n\rangle^2 \exp(-(k/k_o)^2)$,

The characteristic wave scale length k_o^{-1} is assumed to be of the order of the ion Larmor radius ρ_i (all calculations were carried out for $k_o^{-1} = 3\rho_i$). The mixing length theory [26] predicts a density fluctuation level given by: $\delta n/n \sim \sqrt{T_e/T_i}\,k_o^{-1}/L_n$, where $L_n=|d \ln n/dx|$. The spatial distribution of the fluctuation amplitude was adopted, for simplicity, in the form:

$$\langle \delta n/n \rangle^2 = \Delta(\rho\rho_i/a^2)^2,$$

where ρ is the radial coordinate and a the minor radius. The scattering length l_s can be defined as the distance the wave must propagate in order to deflect its $k_\perp$ by an angle of 90^o. The scattering length l_s for a slow wave with a group velocity perpendicular to the magnetic field $v_{g\perp}$ can be calculated according to [24] (see for more details also [1,13]):

$$l_s = v_{g\perp}/\nu_1$$

$$\nu_1 = 2\int_0^{2\pi} K(k_\perp,\beta) S(k_\perp \sin(\beta/2)) \sin^2(\beta/2) d\beta$$

$$K(k_\perp,\beta) = \frac{\pi k_\perp \omega^2}{2v_{g\perp}} \frac{(((\varepsilon-1)\cos\beta+1)^2+g^2\sin^2\beta)^2}{1+(\omega_{pe}/\omega_{ce})^2}$$

Scattering of the waves is modelled in the framework of the ray-trajectory approach using the Monte Carlo method.

b) Fokker-Plank calculations

$$\frac{\partial F}{\partial t}+\nabla\vec{S}=I(F_{m,}F_{1}\mu),\qquad \nabla\vec{S}=\frac{1}{p^2}\frac{\partial}{\partial p}(p^2 S_p)-\frac{1}{p}\frac{\partial}{\partial\mu}(S_\mu\sqrt{(1-\mu^2)})$$

$$S_p=\varepsilon\mu F-D_{LH}\mu(\mu\frac{\partial F}{\partial p}+\frac{1-\mu^2}{p}\frac{\partial F}{\partial\mu})-A(p)\frac{\partial F}{\partial p}+G(p)F,\qquad S_\mu=\sqrt{(1-\mu^2)}(-\varepsilon F+D_{LH}(\mu\frac{\partial F}{\partial p}+\frac{(1-\mu^2)}{p}\frac{\partial F}{\partial\mu})+\frac{B(p)}{p}\frac{\partial F}{\partial\mu}$$

2. Calculation of plasma emissivity and absorption in the EC frequency range

a) Emissivity is expressed in terms of correlation function of micro currents:

$$< j_i^m\, j_l >_{\omega,k}=\frac{e^2 n}{4\pi}\int\sum_n\delta(\omega-k_{//}v_{//}-n\omega_{ce})R_{il}^n F(p)p_\perp dp_\perp dp_{//}$$

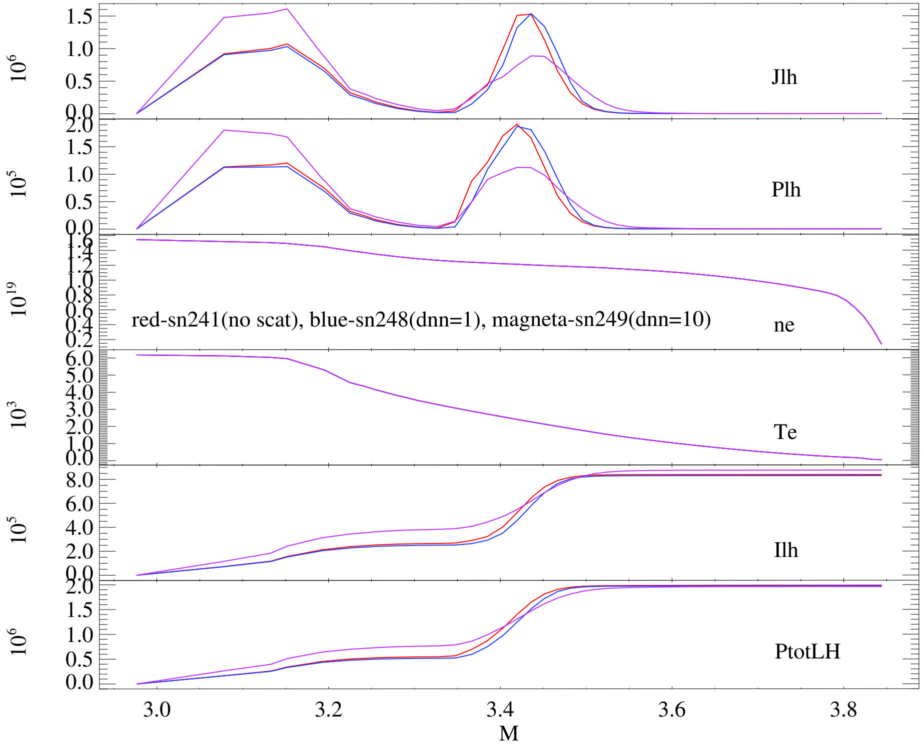
b) Absorption can be deduced from solution of the dispersion relation with proper anti-Hermitian part of the dielectric tensor:

$$\varepsilon''_{ij}(\omega,k)=\frac{e^2 n}{4\pi}\int\sum_n\delta(\omega-k_{//}v_{//}-n\omega_{ce})R_{il}^n\left[\frac{\partial F(p)}{\partial p_\perp}(1-k_{//}v_{//}/\omega)+\frac{\partial F(p)}{\partial p_{//}}k_{//}v_\perp/\omega\right]p_\perp dp_\perp dp_{//}$$

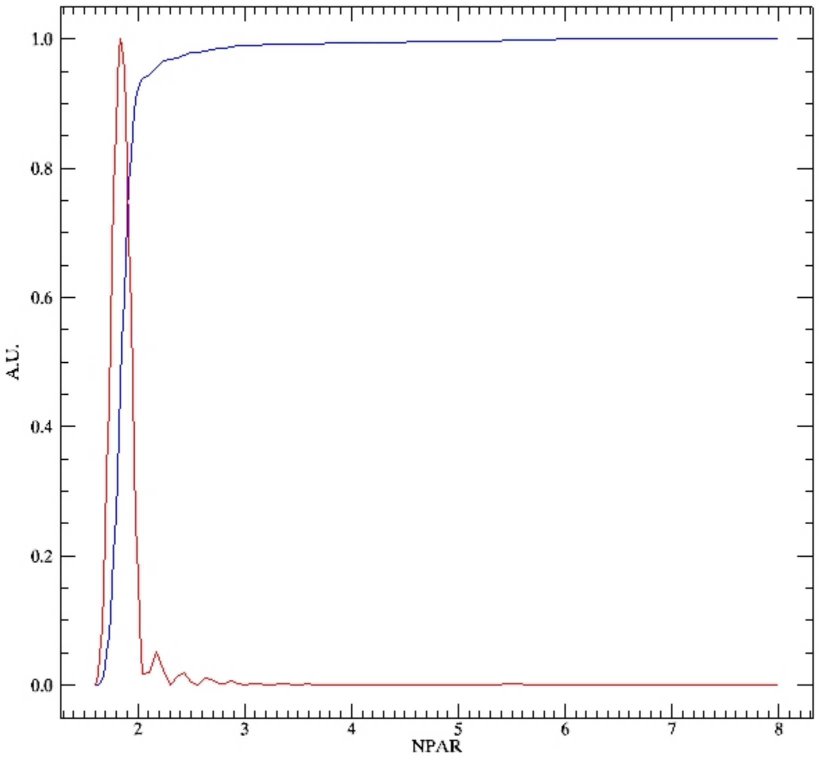
3. Calculation of the local and effective 'radiative' temperature

$$T(\omega,k)_{loc} = \frac{4\pi}{i\omega} \frac{< j_i j_j >_{\omega,k} e_i e_j^*}{(\varepsilon_{kl}^* - \varepsilon_{kl}) e_k e_l^*} \qquad T(\omega,k)_{eff} = 2\int_{R+a}^{R-a} T(\omega,k)_{loc} k_r dr' \times \exp(-2\int_{r@}^{R+a} k_r dr)$$

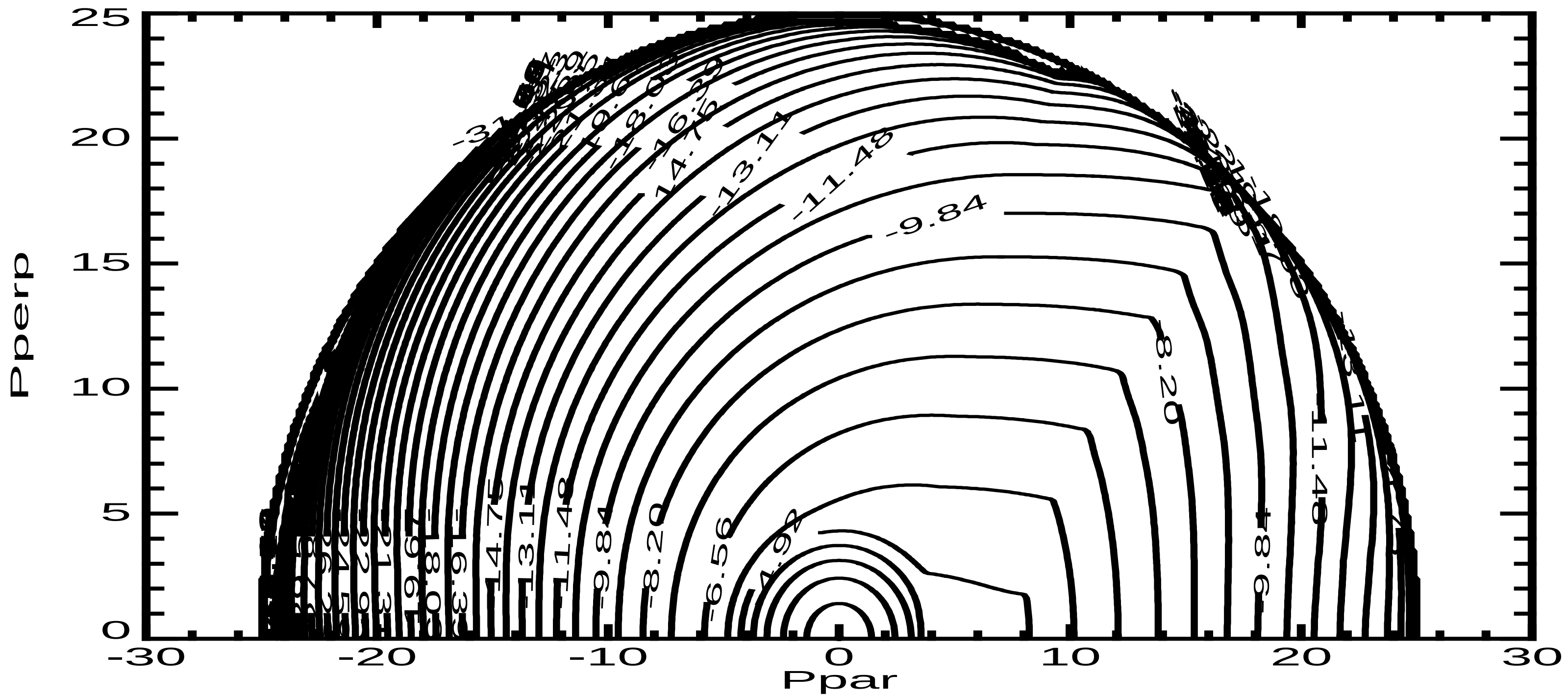
LH power deposition and driven current. #61341, t=42.88s

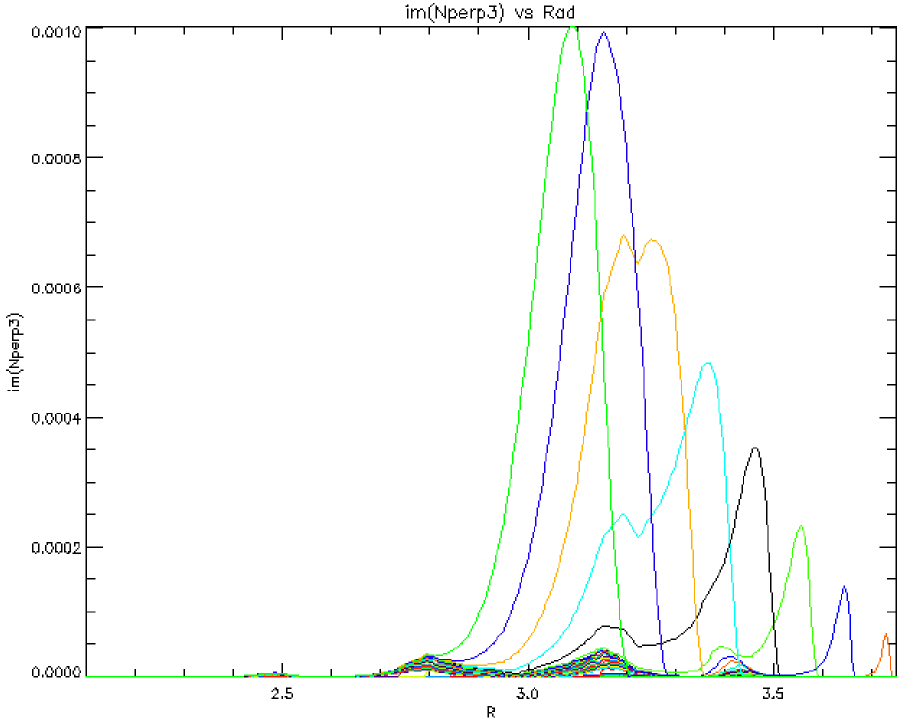


LH LAUNCHER POWER SPECTRUM, PHASING-0^{O}, #61341, T=42.63S

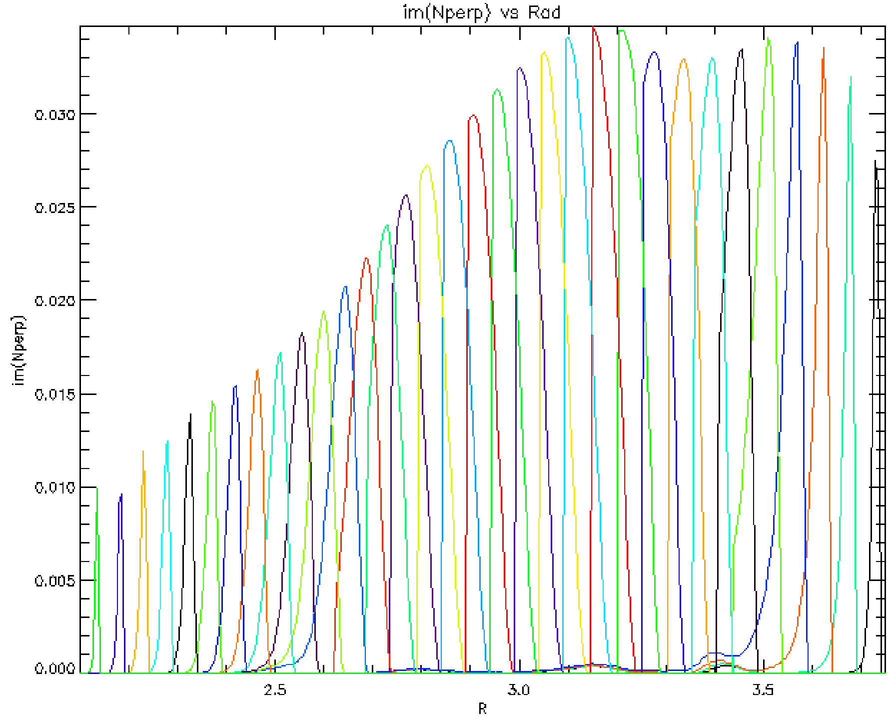


Contour plot of electron distribution function in presence of LHCD

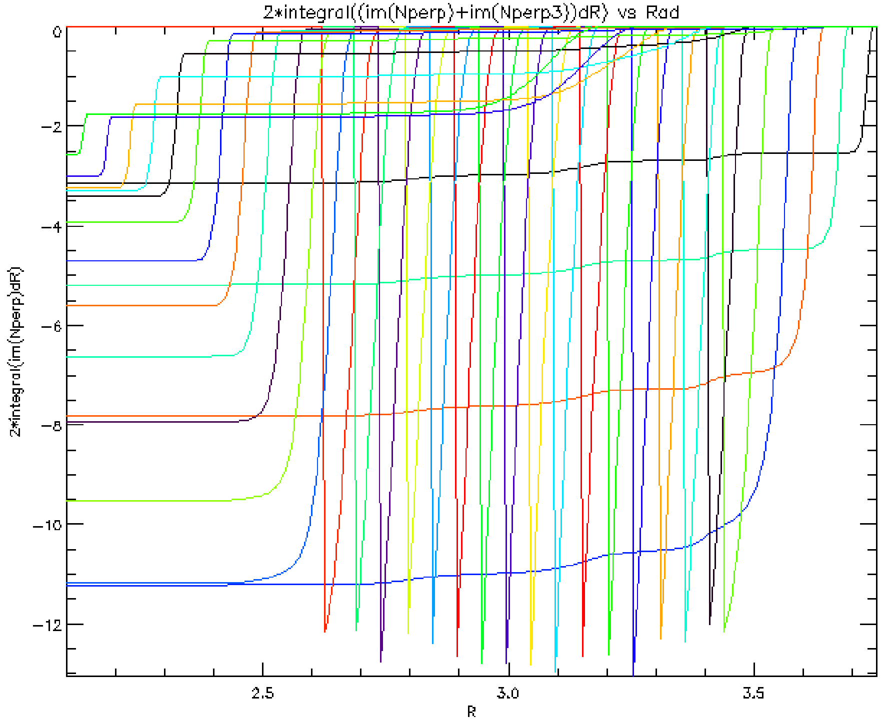




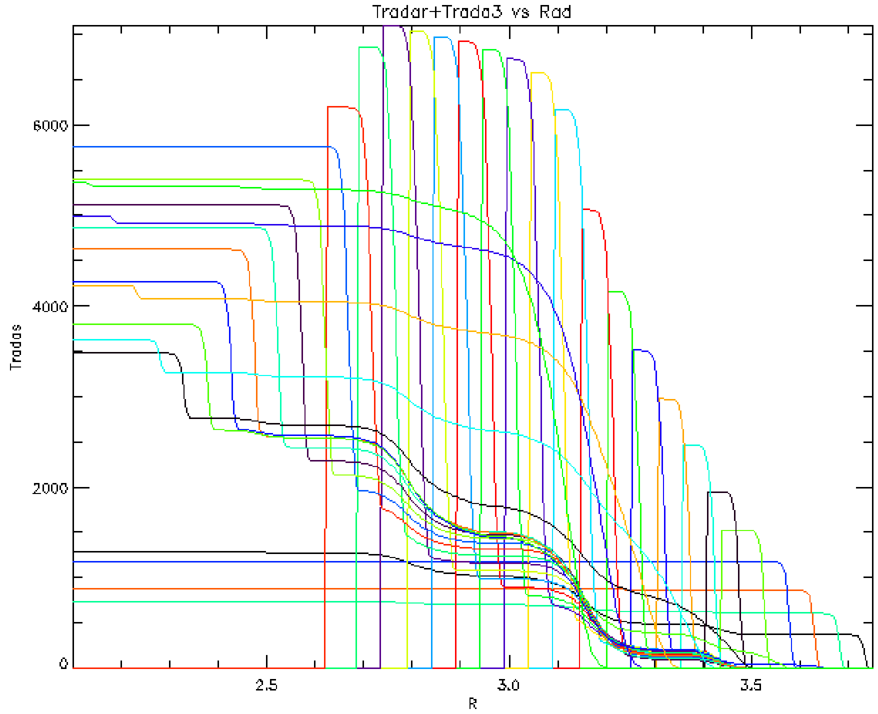
Im(N_{perp}) for third harmonic downshifted emission different frequencies



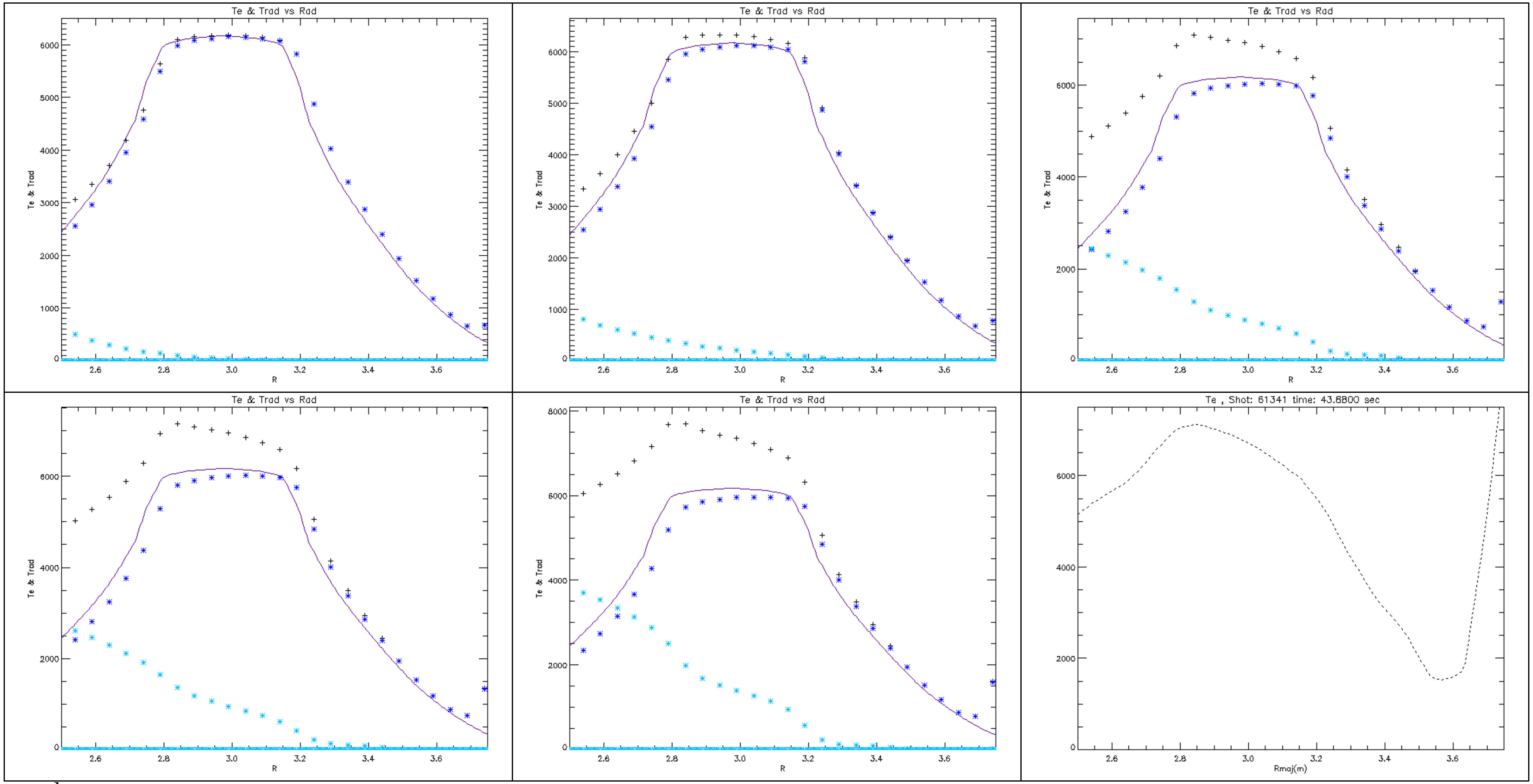
Im(N_{perp}) for second harmonic downshifted emission different frequencies



$$-2\int_{r^@}^{R+a} k_r dr$$



$$T(\omega,k)_{eff} = 2\int_{R+a}^{R-a} T(\omega,k)_{loc}\, k_r\, dr' \times \exp\left(-2\int_{r^@}^{R+a} k_r\, dr\right)$$



2^{nd} harmonic ECE emission temperature. 1)Antenna phasing $+90^o$ ($N_{//max}$≈2.4), 2)Antenna phasing $+45^o$ ($N_{//max}$≈2.1), 3)Antenna phasing 0^o ($N_{//max}$≈1.8), 4)Antenna phasing 0^o ($N_{//max}$≈1.8) with scattering $Rq_{95} << l_s$, 5)Antenna phasing 0^o ($N_{//max}$≈1.8) with scattering $Rq_{95} \approx l_s$, 6)Measured T_e (ECM1/PRFL), #61341, t=43.88s

Summary

- LHCD modelling including effect of wave scattering in JET is being done.
- Code was developed to model EC emission in the presence of LHCD.
- ECE emission during LHCD is being analysed.
- Radiation temperature at the plasma core was calculated and compared with measurements for conditions typical for LHCD preheat.
- First steps have been made to assess the validity of the T_e measurements in the presence of LHCD.

Further steps

- More modelling for current ramp and high density cases.