Calculation of EBW Emission from Nonthermal (EBWCD) NSTX Discharge

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- GENRAY (an all frequencies 3D ray tracing code) calculates electron Bernstein wave emission (EBWE) from thermal or nonthermal distributions.

  -Emission and absorption are calculated at each point along an EBW ray, and the radiation transport eqn is back-solved to the detector.

  -Hot plasma dispersion with relativistic calc of the emission and absrp is used.

- The BXO (Bernstein-X-O mode conversion) emission window is found with a shooting algorithm to obtain the central ray angles for a given receiver (antenna) position giving 100% transmission (Kopecky, Preinhaelter, Vaclavik, J. Pl. Phys., 1969).

  -Alternatively, efficient BX conversions is assumed.

- Finite receiving antenna aperture can be modeled using Mjølhus transmission formula (J. Pl. Phys., 1984) and multiple rays.

- Following, we show calculated EBWE radial profiles for an NSTX experimental profile with thermal distributions, and compare to a case with EBWCD nonthermal distributions from a simulated OXB injection experiment.

Radiation Transport Equation

(Bekefi, p. 38)

Gives radiation intensity I as a function of distance s along rays:

$I =$ Power per unit (area · radian free · steradian) flowing in direction $\hat{s}$

$$n_r^2 \, \hat{s} \cdot \nabla (n_r^{-2} I) = j - \alpha I$$

$n_r^2 \, \hat{s} \cdot \nabla (n_r^{-2} I)$	=	j	−	αI
⇑		⇑		⇑
ray direction		emissivity		absorptivity

$n_r =$ Ray refraction index (cold plasma)

$\hat{s} =$ Ray direction (cold plasma)

$j =$ Power radiated per unit volume, per (radian frequency, steradian)

$\alpha =$ Inverse damping length

▼

At each point along the ray:

$$\alpha = \frac{\omega}{4\pi} \frac{\underline{E}^* \cdot \underline{\underline{\varepsilon}}_{\rm a} \cdot \underline{E}}{|\underline{S}|} \quad , \qquad j = \pi\, n_{\rm r} \left(\frac{\omega}{c}\right)^2 \frac{\underline{E}^* \cdot \underline{\underline{G}} \cdot \underline{E}}{|\underline{S}|} \quad ,$$

$$\underline{\underline{\varepsilon}}_{\rm a} = -\,\pi\, \frac{\omega_{\rm p}^2}{\omega^2} \sum_{n=-\infty}^{\infty} \int d^3p\, U(f)\, \underline{\underline{S}}^{(n)}\, \delta\left(\gamma - \frac{k_{\parallel} u_{\parallel}}{\omega} - \frac{n\omega_{\rm c}}{\omega}\right) \quad ,$$

$$\underline{\underline{G}} = \frac{\pi}{(2\,\pi)^5} \frac{\omega_{\rm p}^2}{\omega^2} \frac{1}{m} \sum_{n=-\infty}^{\infty} \int \frac{d^3p}{\gamma}\, f\, p_{\perp}\, \underline{\underline{S}}^{(n)}\, \delta\left(\gamma - \frac{k_{\parallel} u_{\parallel}}{\omega} - \frac{n\omega_{\rm c}}{\omega}\right) \quad ,$$

$$U(f) \equiv \frac{1}{\gamma} \left[\frac{n\omega_{\rm c}}{\omega} \frac{\partial f}{\partial p_{\perp}} + n_{\parallel} \frac{p_{\perp}}{mc} \frac{\partial f}{\partial p_{\parallel}}\right] \quad ,$$

$$\underline{\underline{S}}^{(n)} \equiv \begin{bmatrix} p_{\perp} \left(\frac{nJ_{\rm n}}{b}\right)^2 & -\,ip_{\perp} \frac{nJ_{\rm n}J'_{\rm n}}{b} & p_{\parallel} \frac{nJ_{\rm n}^2}{b} \\ ip_{\parallel} \frac{nJ_{\rm n}J'_{\rm n}}{b} & p_{\perp} \left(J'_{\rm n}\right)^2 & ip_{\parallel} J_{\rm n} J'_{\rm n} \\ p_{\parallel} \frac{nJ_{\rm n}^2}{b} & -\,ip_{\parallel} J_{\rm n} J'_{\rm n} & \frac{p_{\parallel}^2}{p_{\perp}} J_{\rm n}^2 \end{bmatrix} \quad ,$$

$$\underline{S} = \frac{1}{8\pi} \; |E_0|^2 \cdot \text{edenfac} \cdot \underline{V}_g$$

group velocity

$$\frac{(1/16)\,\pi\,[\underline{B}_0 \cdot \underline{B}_0^* + \underline{E}_0 \cdot \frac{\partial(\omega\underline{\varepsilon}_h)}{\partial\omega} \cdot \underline{E}_0]}{(1/8)\,\pi\,|E_0|^2}$$

(= 1 for free space)

- Rays, polarizations, edenfac, and group velocity are determined from cold plasma (except polarizations from warm plasma, for first and second harmonic).

Multiple Reflections

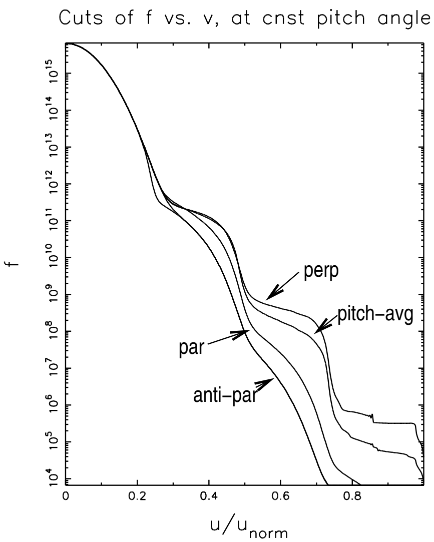
$$I_{0t} = I_0 \left(1 + r\,e^{-\tau} + r^2\,e^{-2\tau} + \ldots\right)$$

$$= I_0 \,/\, \left(1 - r\,e^{-\tau}\right)$$

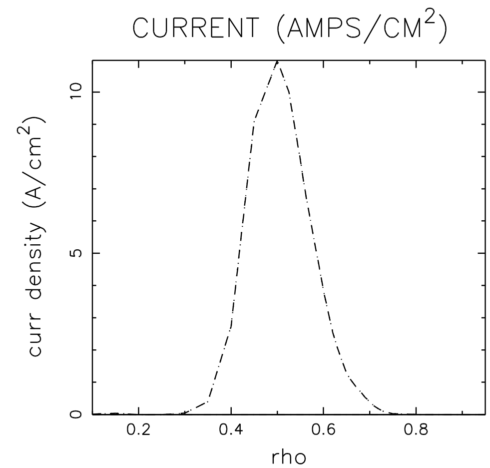
CompX

Comparison of EBWE from Thermal and Non–Thermal NSTX Shot (113544) [With next few slides]

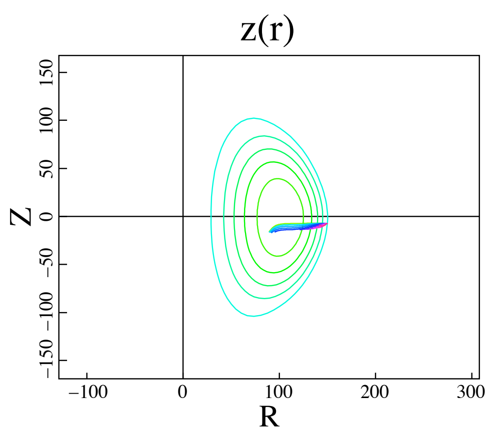
Non–Thermal Dististributions obtained vs rho (here = 0.59)

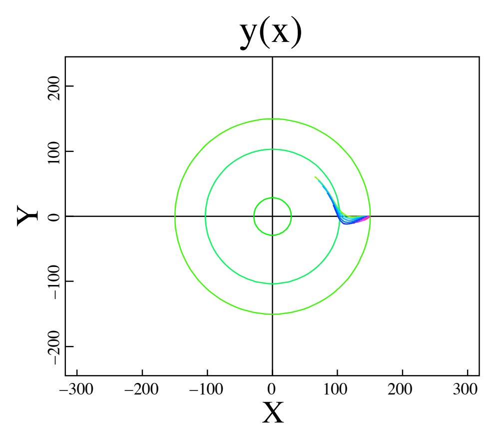


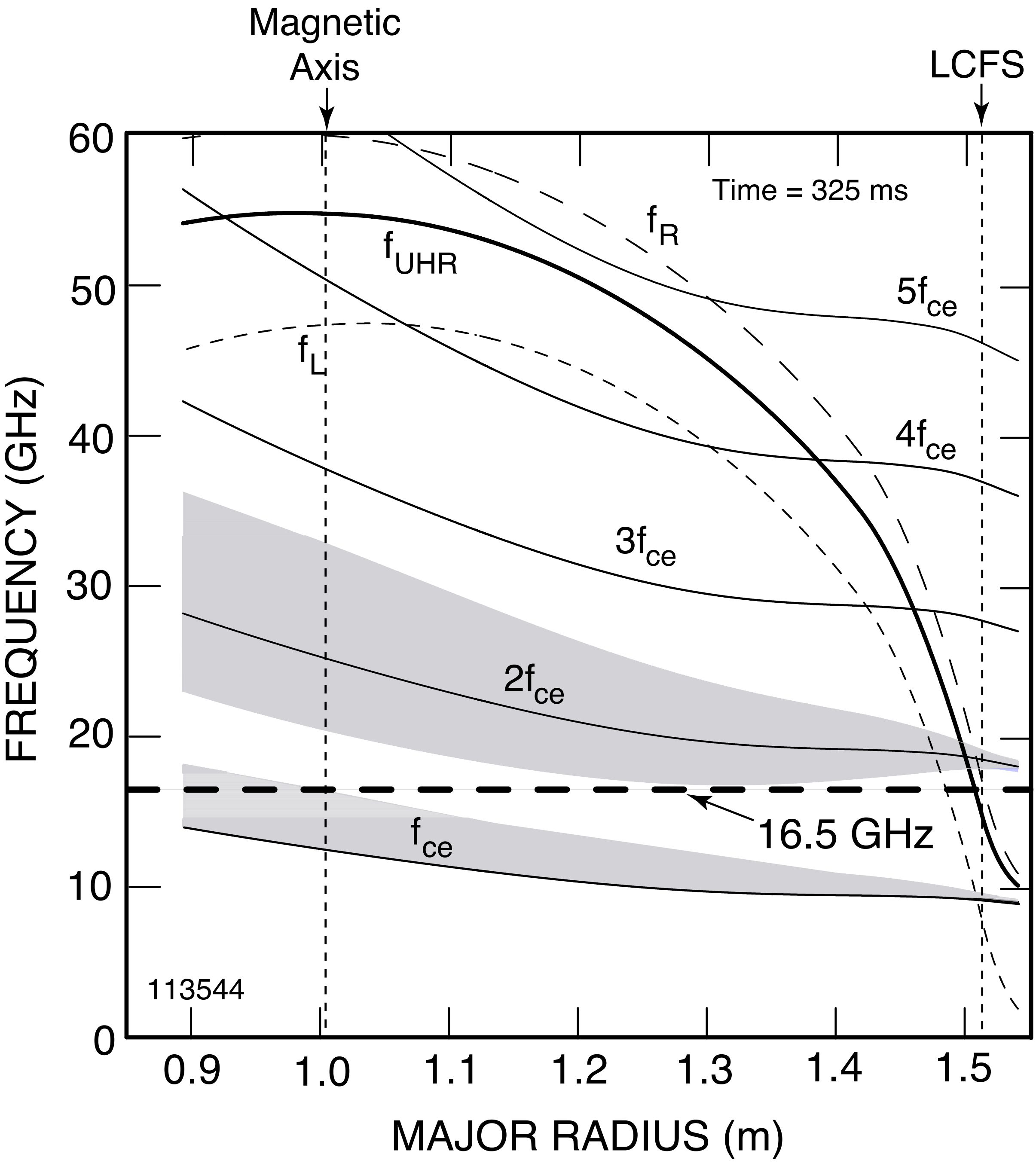
Radial variation of EBWCD vs rho. 1MW EBW, 47 kA.



CX– and top–view of EBWE rays, 16–18 GHz, XO–mode conversion

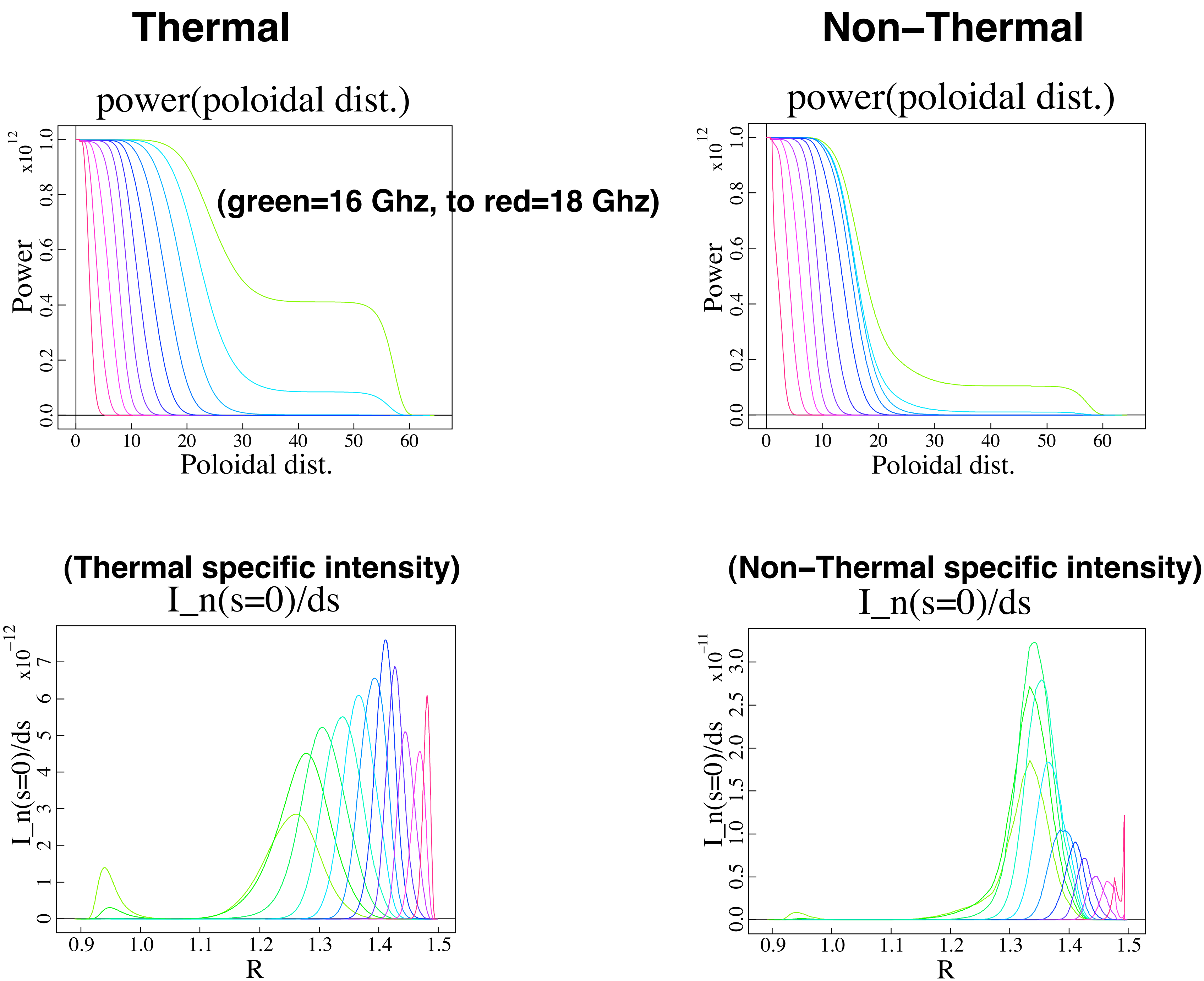






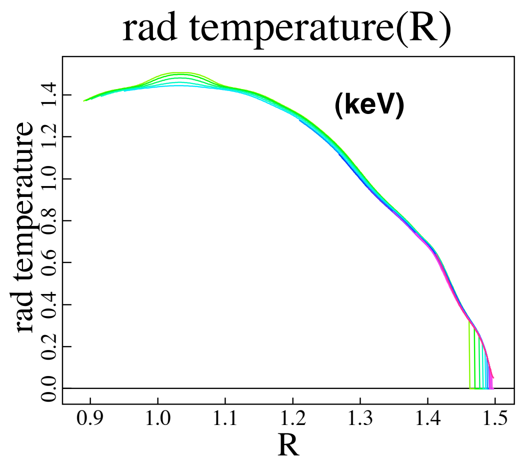
Magnetic
Axis
LCFS
Time = 325 ms
f_R
f_{UHR}
$5f_{ce}$
f_L
$4f_{ce}$
$3f_{ce}$
$2f_{ce}$
16.5 GHz
f_{ce}
113544
60
50
40
30
20
10
0
FREQUENCY (GHz)
0.9
1.0
1.1
1.2
1.3
1.4
1.5
MAJOR RADIUS (m)

Figure 4

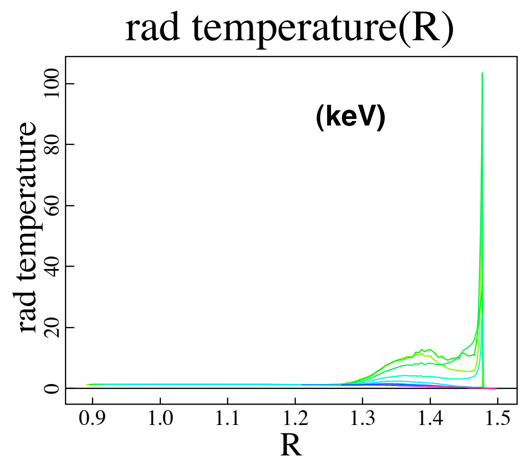

Thermal
Non−Thermal
power(poloidal dist.)
(green=16 Ghz, to red=18 Ghz)
Power
x10^12
Poloidal dist.
(Thermal specific intensity)
(Non−Thermal specific intensity)
I_n(s=0)/ds
x10^-12
x10^-11
R

Radiation temperature along the ray (emission/absorption):

Thermal

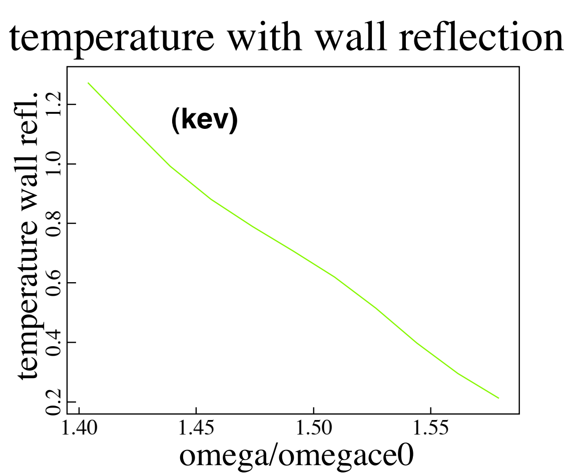


Non–thermal

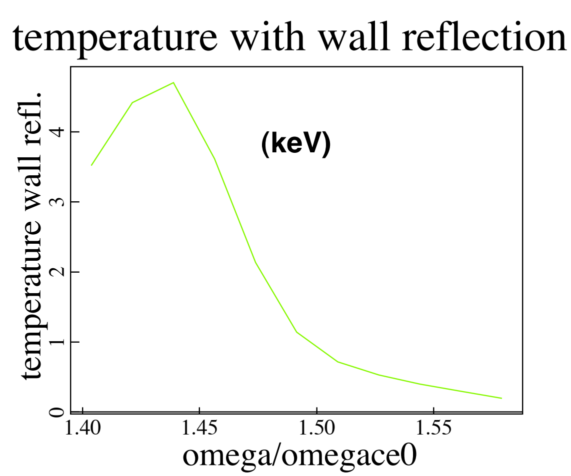


Calculated radiation temperature at the detector

Thermal



Non–thermal



Conclusions

- Electron Bernstein wave emission can give the radial profile of T_e for lower beta thermal NSTX shots through the BXO channel.

- The EBWE will be sensitive to nonthermal deviations of the electron distribution. The calculations show an intermediate temperature between thermal and tail-nonthermal temperature from 1 MW .

- Not shown is EBWE calculated for a high (40%) beta plasma. The BXO channel was only sensitive to the plasma edge (outer 5 cms). However, the BX channel, with smaller $n_{\|}$, could penetrate to the plasma interior and was also sensitive to nonthermal electrons.