Joint Varenna - Lausanne International Workshop Varenna 2008

Monte Carlo ICRH simulations in fully shaped anisotropic plasmas

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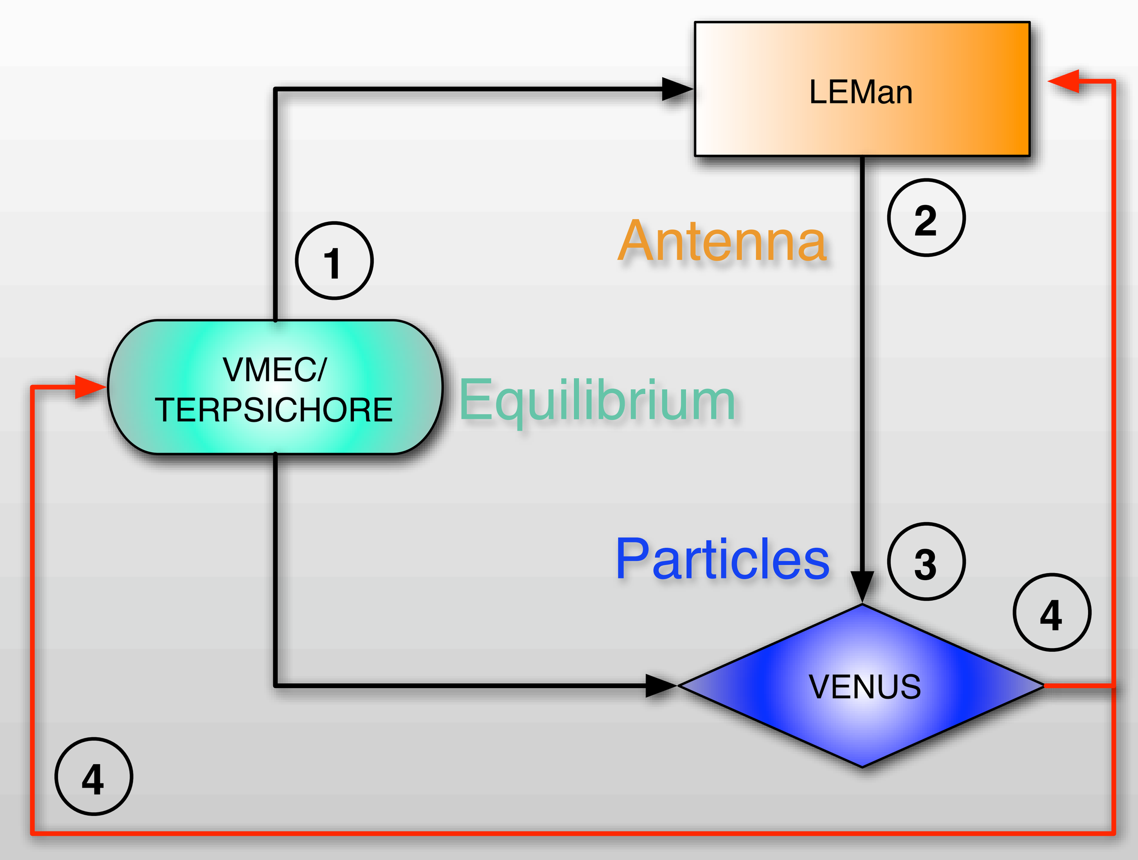
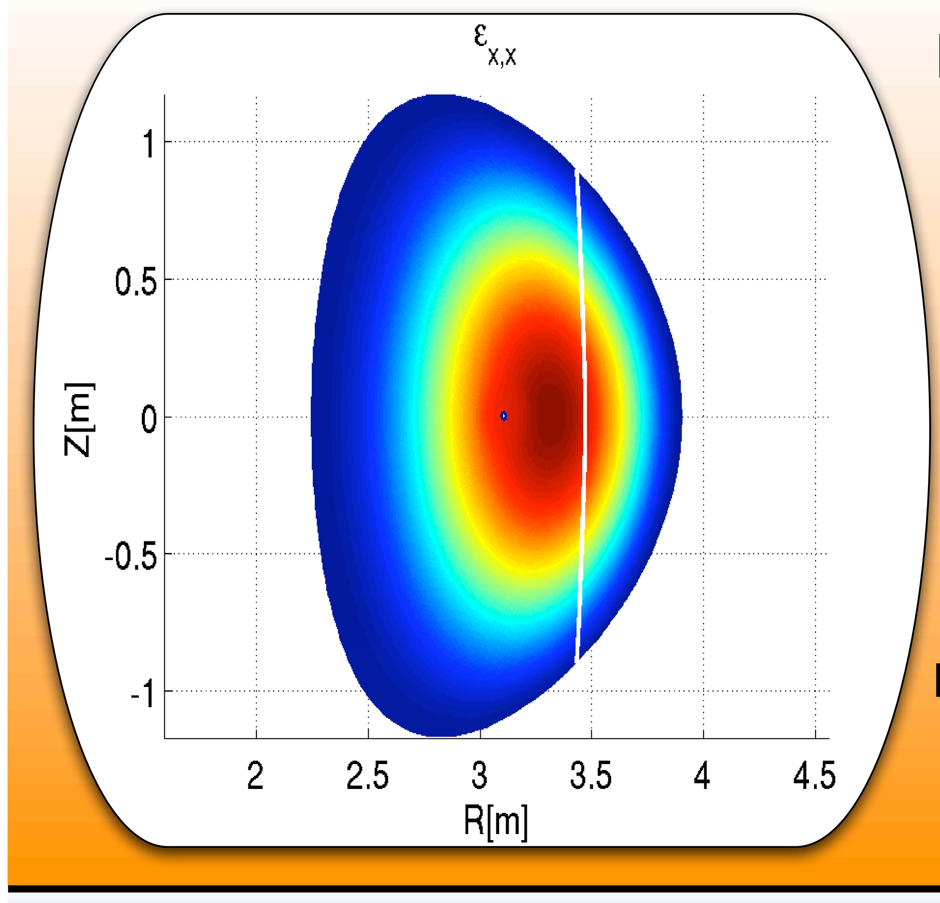
Overview: Self-consistent model of ICRH

1. VMEC[1] for general (2/3D) MHD equilibrium with full shaping and pressure anisotropy. Mapping into Boozer coordinates by TERPSICHORE[2].
2. Full-wave code LEMan[3,4] calculates power deposition and electric field strength using a warm model. Three species used: Thermal electrons and ions (Maxwellian, static, D) and fast ions (Bi-Maxwellian, dynamic, H)
3. Single particle code VENUS[5,6] combines equilibrium and ICRF power deposition for the evolution of the distribution function of the fast ions including full orbit effects.
4. Updated distribution function moments are fed back into VMEC and LEMan.



Equilibrium with bi-Maxwellian distribution function for including anisotropy: $F_h(\psi,E,\mu) = \left(\frac{m}{2\pi}\right)^{3/2} \frac{n_c(\psi)}{T_\perp(\psi)T_\parallel^{1/2}(\psi)} \exp\left[-\frac{\mu B_c}{T_\perp(\psi)} - \frac{|E-\mu B_c|}{T_\parallel(\psi)}\right]$



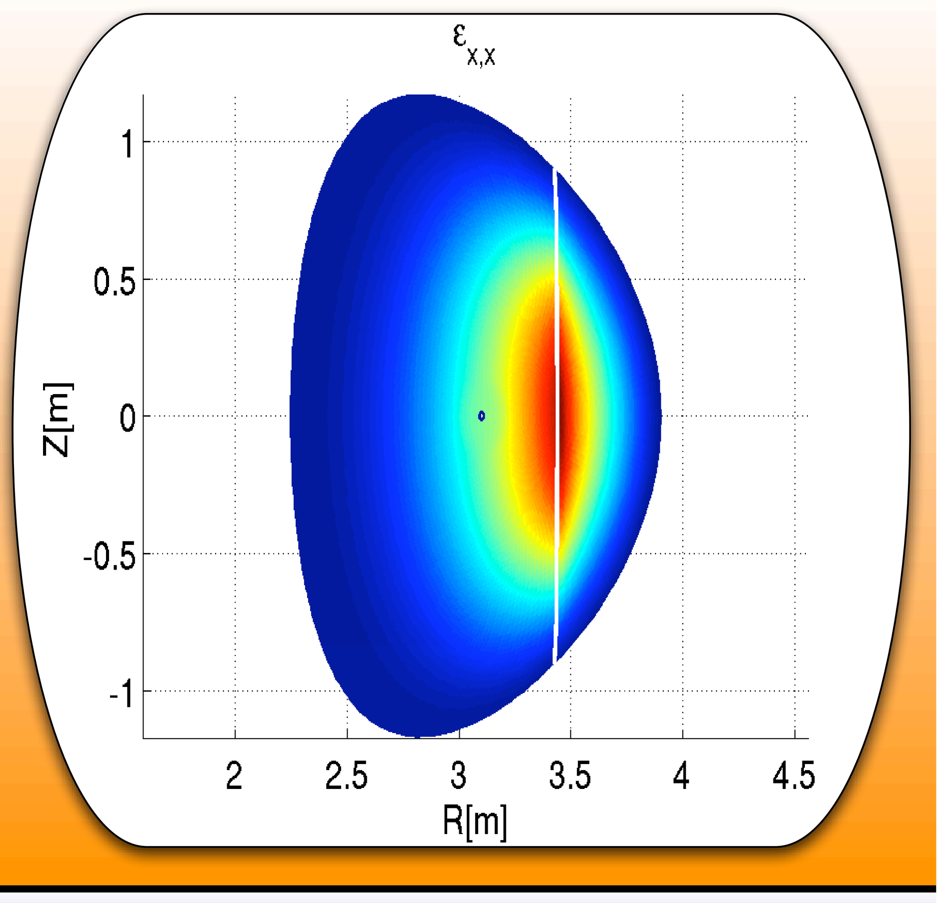
Newly derived dielectric tensor for fast particles (from Bi-Maxwellian) brings dependence on the magnetic field strength, position of the resonant layer and anisotropy, and can thus have a strong poloidal dependence.

$$\epsilon^h = \epsilon^h\left(\frac{B_c}{B}, \frac{T_\perp}{T_\parallel}, T_\parallel\right) \Longrightarrow \epsilon^h = f(\theta)$$

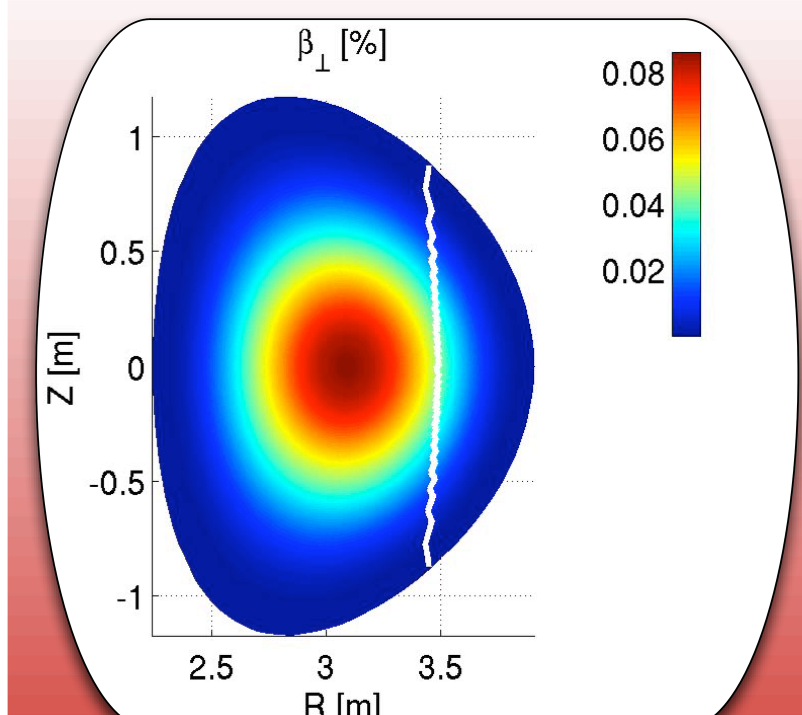
Figures: Dielectric tensor element $\epsilon^h_{x,x}$ for LFS heating.

Left: Isotropic case $T_\perp/T_\parallel = 1$ Right: Anisotropic case $T_\perp/T_\parallel = 10$

R_0=3.1m, a=0.95m, κ_a=1.4, δ_a=0.4
B_0=3.4T, B_c=3T, β_{th}=0.3%, β_h=0.2%, T_{th}=14keV, $T_{\perp,h}$=250keV, f=46MHz

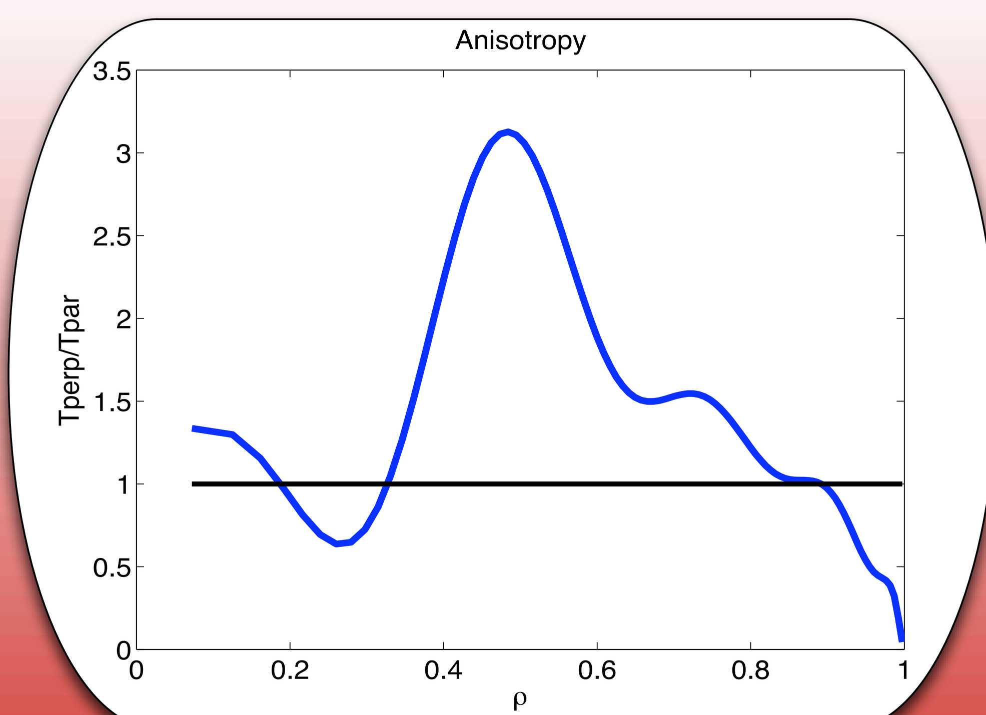


Monte-Carlo operators: Coulomb scattering $\Delta^C(\frac{v_\parallel}{v}, E)$, ICRH kicks $\Delta^{ICRH}(v_\parallel, v_\perp)$ Outputs: $f(s,\theta,v_\parallel,v_\perp), p^h_\parallel(\psi,\theta), p^h_\perp(\psi,\theta), n^h(\psi), \frac{T_\perp}{T_\parallel}(\psi)$



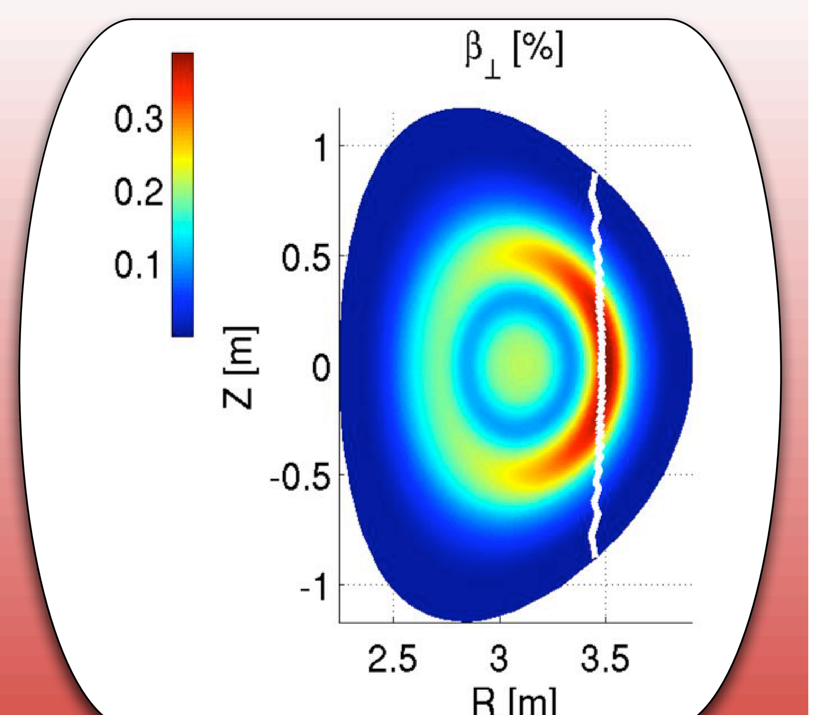
Initial perpendicular beta.

VENUS →



Anisotropy $T_\perp/T_\parallel$ as a function of $\rho = r/a$.
In black the initial isotropic line.

VMEC →



Diamagnetic perpendicular beta.
In white the resonant layer $B = B_c$

ICRF: 7MW total absorbed power, 46MHz, results shown after 1ms

RESULTS & CONCLUSIONS

- Effects of anisotropy and full shaping on both the MHD equilibrium and the dielectric tensor have been explored. In particular, it is shown that the dielectric tensor becomes dependent on poloidal angle. Also, the anisotropic effects dominate the dielectric tensor.

- Using single particle simulations it could be demonstrated that anisotropy develops due to ICRH. Also, the changing of the equilibrium was successfully fed back into the equilibrium.

FUTURE WORK

-The effect of newly arising anisotropy on the wave field can be explored as well as the impact of the changing wave field on the single particle orbits.

-These results show only one iteration: In order to make the model self-consistent, more iterations are necessary and as a result a new converged equilibrium with ICRH should be found.

-For validation of the code, benchmarking will be important, e.g. with the SELFO code for circular and isotropic equilibria.

References

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Acknowledgments

This work was supported by part by the Swiss National Science Foundation.
Also, the authors would like to acknowledge the help of L. Villard.