Coupled Ray-Tracing and Fokker-Planck EBW Modeling for Spherical Tokamaks

Jakub Urban

Josef Preinhaelter, Gary Taylor, Joan Decker, George Vahala, Linda Vahala

A short intro on EBW

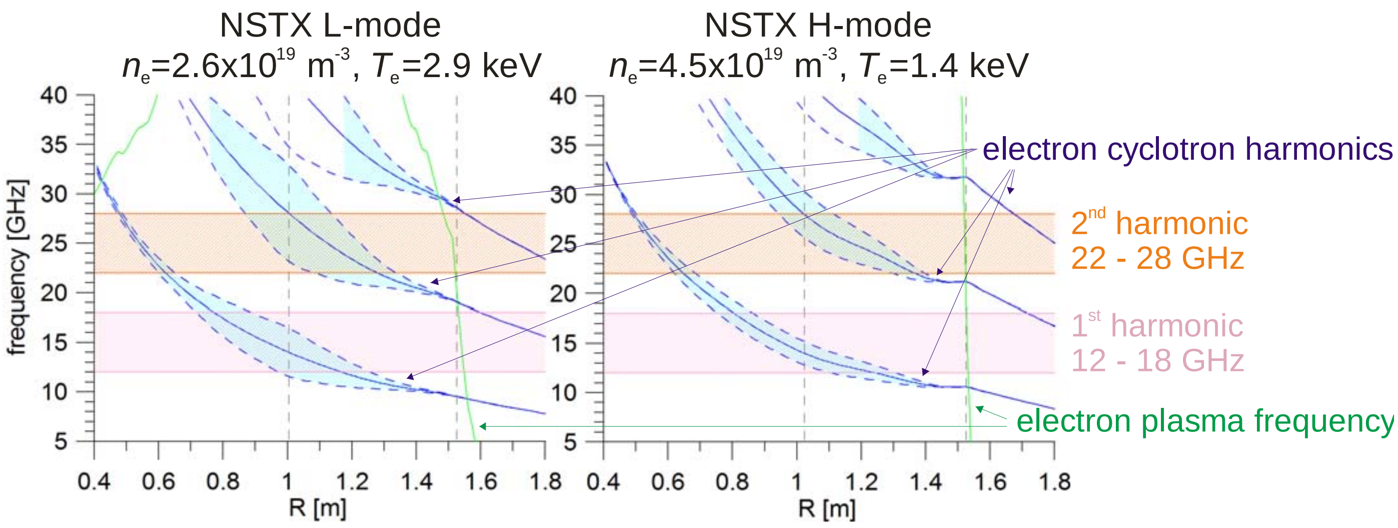
- **Electron cyclotron** (EC) heating an current drive is important for magnetic confinement fusion
- “Standard” **EC waves are cut off** in spherical tokamaks (STs): $\omega_{pe} \gg \Omega_{ce}$
- **Electron Bernstein wave (EBW)** must be used in STs
  - no upper density cut-offs
  - efficiently absorbed at any harmonics
  - efficient current drive because of interaction with suprathermals
  - must be excited by O- or X-modes
  - more difficult to control

The EBW simulation

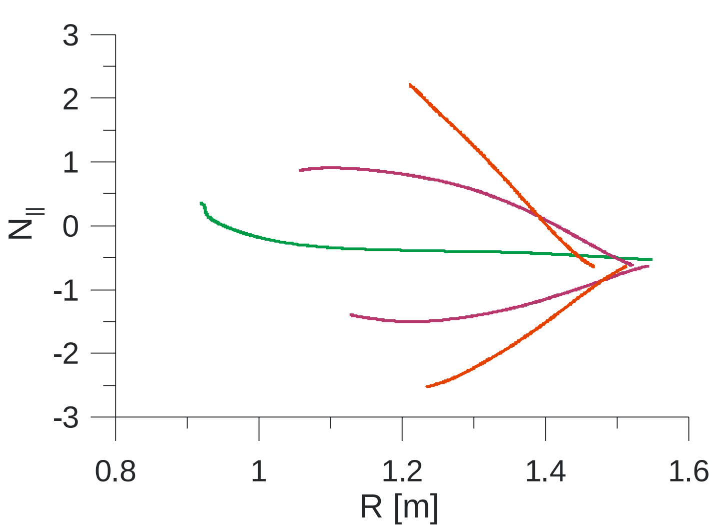
- **Two coupled codes**
  - **AMR** (Antenna—Mode-conversion—Ray-tracing)
  - **LUKE** (3D Fokker-Planck code)
  - (similar to GENRAY + CQL3D)
- **Antenna aiming determined** by the O-X-EBW optimum
- **EBW propagation** inside the plasma well described by **ray tracing**
- **Quasi-linear damping and current drive** calculated by **LUKE**

Injection and target plasma parameters

- **Only two** EBW launching **parameters** can be chosen **arbitrarily**
  - **frequency**
  - **vertical antenna position**
  - (two O-X-EBW optimums exists in opposite toroidal directions)
- Calculations carried out
  - 1 MW power
  - typical NSTX L-mode (and H-mode)
  - 1^{st} and 2^{nd} harmonic



Typical EBW behavior



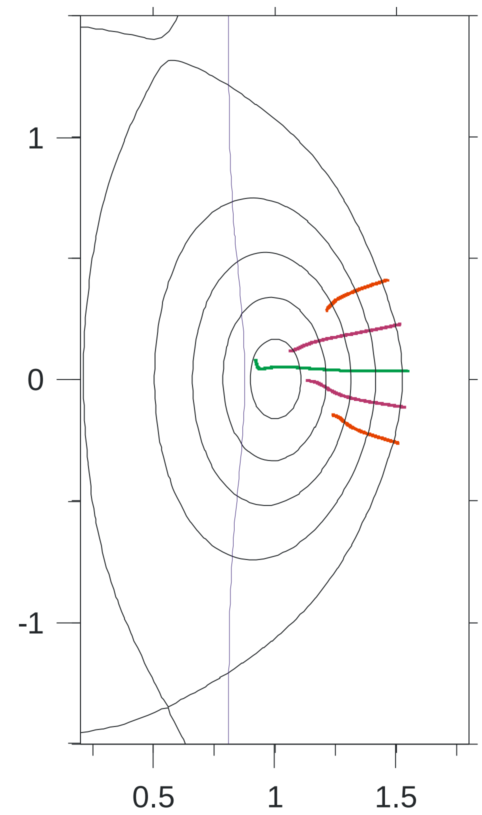
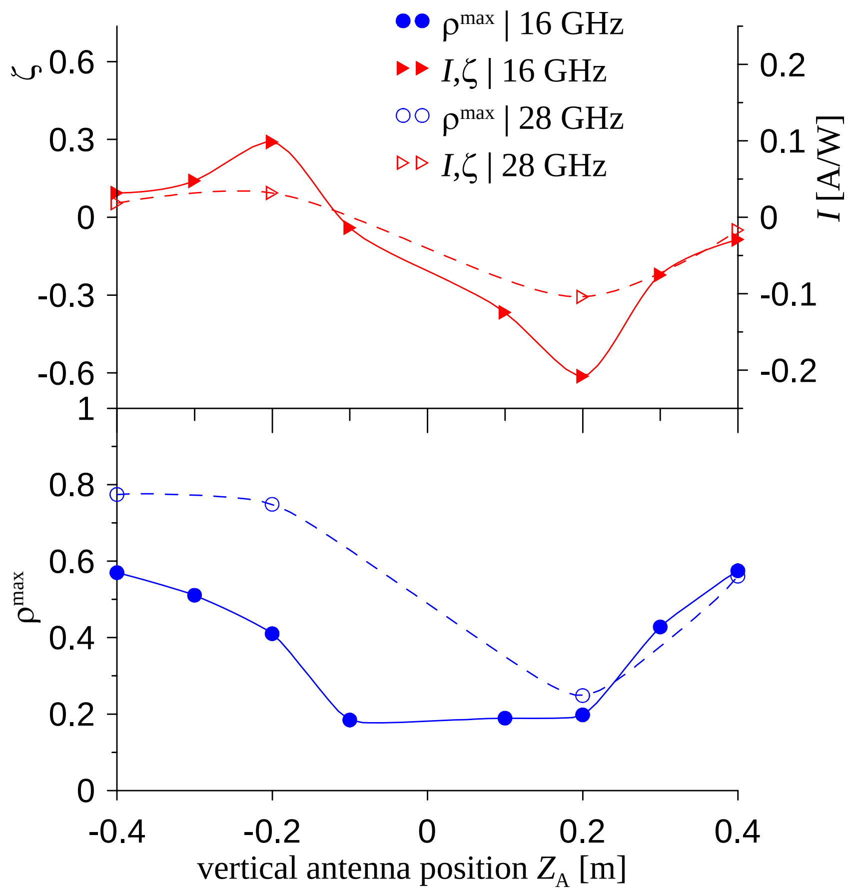


Fig. 2. Ray $N_{||}$ (top) and trajectories (right) of 16 GHz EBWS in L-mode plasma for Z_A=0,±0.2,±0.4 m.

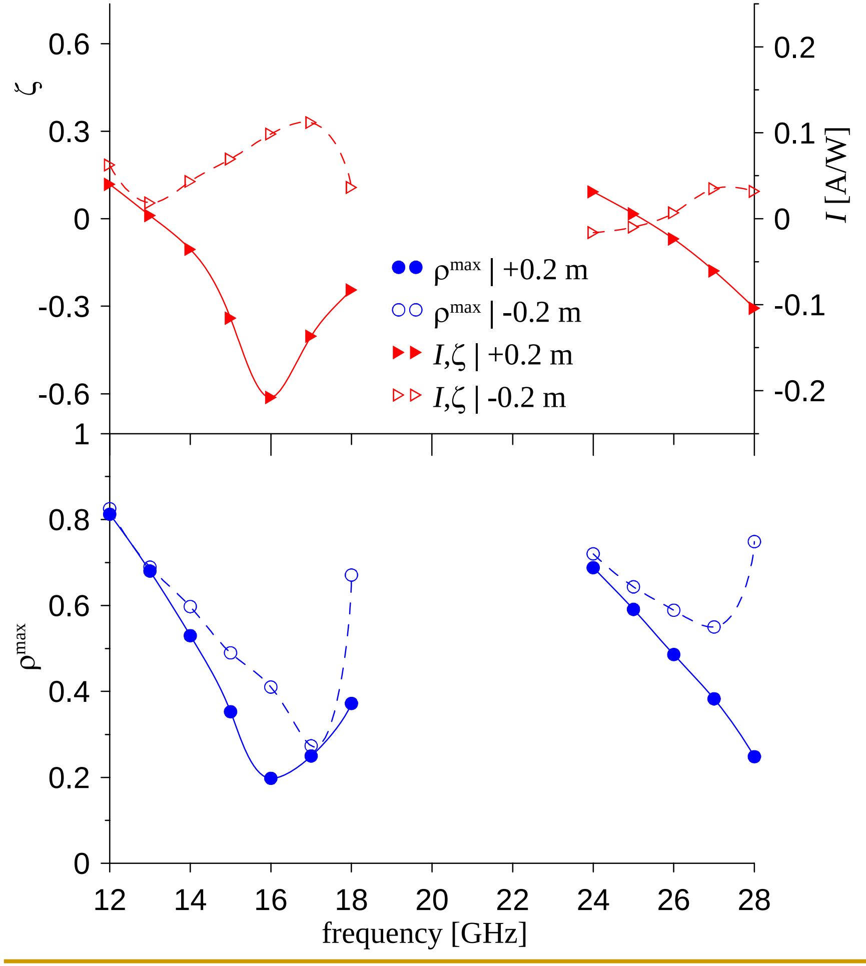
Mid-plane launch can be favorable for **central heating**, but is very **unfavorable for current drive** because of the small (and oscillating) $N_{||}$.

Antenna vertical position scan



- The **current direction** is determined
  - by the vertical launch position, which determines the $N_{||}$
  - by the damping location, which determines the current drive mechanism: Fisch-Boozer at smaller radii, Ohkawa at the edge

Frequency scan



- Frequency dependence qualitatively similar to the antenna position dependence.
- Current drive typically more effective at the 1st harmonic.

Conclusions and outlook

- AMR + LUKE is capable of complex and realistic EBW heating and current drive simulations.
- The excited EBWs can efficiently be absorbed and drive current at certain radii. The current direction is opposite for above / below mid-plane launch.
- The deposition location can be controlled by changing either Z_A or the frequency. The frequency-based control provides larger radial range.
- More simulations have to be done and analyzed
  - NSTX H-mode
  - NHTX
  - other devices (MAST, MAST Upgrade)
- EBW H&CD robustness and sensitivity will be addressed.