Observation of Electron Bernstein Wave Heating in the RFP

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Outline

• Reversed field pinch and EBW overview
• Experimental setup and diagnostics
• Heating observations
• Conclusions
EBW Allows Heating in Overdense Plasma

- Like ECH, EBW drives cyclotron motion
- EBW provides localized heating where ECH is prohibited in an overdense \((\omega_{pe} > \omega_{ce})\) plasma
- CD profile control can stabilize tearing modes, provide better-confined RFP plasma
- EBW Heating can
  - Test local Beta limits
  - Heat pulse propagation
  - Test fast electron confinement
Motivation for EBW Studies in the RFP

• High density stellarators likely to need EBW
• The RFP is an excellent test bed for EBW physics in a stochastic field. Applications are:
  – Stochastic edge in tokamak w/ RMP ELM suppression
  – Handoff in current drive in ST following helicity injection

• This work: confirmation of EBW propagation and deposition control by the study of heated electrons in the RFP
  – Measurement of radial wave accessibility in MST
  – Confirmation of EBW propagation across and heating in a stochastic field
The MST Reversed Field Pinch

- $R=1.5\text{m}$, $a=0.52\text{m}$, $I_p=50-550\text{kA}$, $<n_e>\sim0.5-2\times10^{13}/\text{cc}$
- Equilibrium defined by self organization of plasma current
- Expected deposition radius is a function of $I_p$
- Overdense, $R$, $L$, $UH$ layers at $5.5\text{GHz}$ within a few cm of the edge
- EBW mode conversion, coupling previously confirmed
- EBE radiometry confirms accessibility through reciprocity (ray comes out implies ray goes in)
- No high field side
- Cutoffs surround plasma
- Steep edge density gradient allows efficient mode conversion to EBW
EBW Absorbed on Doppler Shifted ECR Location

\[ \omega_{rf} = n \omega_{ce} - k_v v \]

\[ l_p = 305850. \]

RF 5.5GHz
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EBW Experiment Overview

- Heating at 5.5GHz via XB mode conversion in the near field of a waveguide antenna.
- Forward power limited to ~150kW, maximum pulse length ~3ms
- Measured coupling: 60-70% of forward power
- Target bremsstrahlung required due to low launched RF power in these experiments
- Insertable probe and fixed limiter independently measure passing and trapped electrons
A distribution of targets detect heated electrons.

Single photon counting HXR

EBW Antenna

Target Probe

Limiter

Poloidal Cross Section (a)

Outboard Limiter

Banana Orbit

HXR6

HXR12

Probe1
Trapped electrons drift toroidally.

Trapped electrons drift in banana orbits to target probe ~180 degrees away.

Passing electrons strike limiter.
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EBW Heating Overview

- Direct probing of radial profiles maps deposition location
- Measurement of electron population after RF pulse termination measures electron confinement time
- Net RF $<<$ ohmic heating (2MW), no temperature rise in plasma is expected or observed
  - No observation on Thomson diagnostic
- Absorption on doppler shifted resonance generates suprathermal electron tail
The EBW heats electrons in the RFP
Porthole in shell generates $|B|$ field error

Edge field reduction extends ~1 porthole diameter into plasma

In absence of field error, EBW reaches 20cm depth

Interruption of wall current generates field error
Field error introduces edge harmonics

Field Line Plot

Reduction of edge field introduces harmonic near wall

\[ n=1 \]

\[ n=2 \]

\[ |p=320 \text{ [kA]}, 5.1 \text{ cm Porthole} \]
Porthole field error limits accessibility window

Mode conversion at UH (red)

Depth [cm]

Without Porthole Error

With Porthole Error

Deviation due to porthole field error

Porthole field error limits accessibility

lp [kA]

n=2

n=1
Window narrows at high harmonics

Expected depth vs plasma current
Absence of limiter emission indicates accessibility inside LCFS.
Probing of radial profile maps deposition location.

\[ \langle r \rangle = \frac{\sum \varepsilon r}{\sum \varepsilon} \]

Change in deposition is subtle, however with repeated measurement...
A clear trend in deposition location is observed.
Trapped and passing electron confinement timescales differ

180deg away, outboard side, sig dominated by trapped electrons

15deg away, inboard side, sig dominated by passing electrons

$I_p = 240kA$
Field stochasticity causes trapped/passing timescale difference

- Measurements for 4cm probe depth
- Confinement time for trapped electrons ~17us
- Confinement time for passing electrons ~20-50ns
- Confinement time limited by transport in the RFP, not collisions

Parallel velocity difference between passing and trapped electrons

\[ D_\perp = v_\parallel D_m \]

\[ I_p = 240 \text{kA} \]
Reduced stochasticity improves confinement time

$I_p = 240kA$
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• The first RF heating in the RFP has been observed on MST using the EBW for harmonics n=1-7
• RFP transport limits fast electron confinement
• Deposition controllable with Ip
• Observation of EBW mode conversion in and propagation across a stochastic magnetic field
• EBW heating in Beta~15% plasmas
• Radial accessibility is limited to r/a > 0.8 (~10 cm) by porthole field error in a thick-shelled device
• Accessibility in a device with actively controlled saddle coils(RFX) is likely to be r/a> 0.5
Questions?