XP** W-P ET: Absorption of HHFW on Beam Ions in NSTX

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Goal: Extend investigation of high harmonic ion cyclotron absorption on beam ions of Rosenberg and of Heidbrink to evaluate:

- competition between core absorption on electrons and beam ions and edge absorption by PDI, sheaths, etc.
- attempt to find parameters that substantially affect the strength of the cyclotron harmonic damping other than launch phasing previously identified

- Important to understand whether ion damping is in agreement with models or not, for future applications of HHFW in STs
  - So far, agreement between various models when applied to DIII-D case is not very good, for reasons that are under ongoing study
  - It seems that damping on 8th harmonic in DIII-D appears weaker than predicted, at least at certain angles of beam injection

Background: absorption mechanisms for HHFW

HHFW damping is by at least three different mechanisms:

- 1) Absorption on electrons
  - by Landau damping, hence stronger at higher k-parallel
  - intended to be dominant in NSTX under most conditions, especially high electron beta
  - should lead to absorption in core, though should be so strong that deposition might be peaked off axis at the highest electron betas
- 2) Absorption on ions
  - by ion cyclotron harmonic damping at the many harmonic layers
  - should be entirely dominated by absorption on fast ions as they slow down towards the bulk if significant population of such fast ions are present
- 3) Edge absorption
  - Many possible different mechanisms: sheath dissipation, radiation from vessel gaps, PDI
  - PDI relatively well documented, CHI gap now instrumented

- Partition between these mechanisms, and hence between core and edge absorption, and between ion and electron absorption in core, is determined by relative strengths of single pass (or bounce) damping
  - For example, if edge absorption per bounce is equal to per-pass absorption in core, only half of the rf power will show up in the core

Background: previous results from NSTX, DIII-D

Heidbrink (1999):

4th harmonic absorption on deuterium beam can be quite strong at 2 T (60 MHz) in DIII-D

5th harmonic absorption at same BT, higher frequency - weak

Roseberg (2003):

HHFW absorption on beam ions on NSTX can be very substantial, leading to a tail above the injection energy and enhancement of neutron rate

Tail size decreased with increasing BT, decreasing k-parallel

Pinsker (2005):

- Compared 4th and 8th harmonic absorption on DIII-D at fixed BT (2 T)
- 8th harmonic weak and nearly independent of beam angle
- 5th and possibly 6th harmonic at fixed frequency (lower BT) both strong

Heidbrink (2006):

- Studied effect of HHFW on *AE modes, used only high k-parallel phasing
- 9-11th harmonic absorption strong nearly independent of beam angle, beam energy
- Possible density effect: later pulse (higher density) had bigger tail at smaller rf power

Expectations from simple theoretical considerations

For NSTX-like conditions:

- Extremely high k-perp*rho means that absorption will be strongest on fast ions at an energy between bulk and injection energy (injection energy is well past peak in Bessel functions, as per Ono [1995])
- So expect rather weak dependence on injection energy
- Absorption should be so strong that global absorption would be total and independent of variations of beam geometry, injection energy, harmonic number, etc. *unless* edge absorption is comparable per bounce to absorption at cyclotron resonances per transit of the layer
- In that case, still expect no dependence on beam variations, etc. since those things should not affect edge absorption per bounce, but global absorptivity will be less than 100%
- On the other hand, varying edge absorption strength (for example, changing gaps and other SOL density variations) should, while not affecting core absorption processes, change the partitioning between core and edge absorption and hence, change the tail size!
- Should avoid changing parameters that simultaneously change edge processes and expected core absorption (such as k-parallel or BT)

Experiment to test these ideas

- Vary central absorption strength without changing edge absorption
  - This is what was done, partially, in the Ruskov/Heidbrink experiment
- Separately, vary the edge absorption without affecting the central absorption
  - Varying details of SOL geometry by changing inner and/or outer gap
- Compare effect of these separate variations on tail energy, global absorption efficiency
  - Looking for effect on global absorptivity due to changes in edge parameters along with no effect on global absorptivity from changes in central absorption, as evidence of comparable edge and core absorption

Proposed Run Plan:

1. Set up stable shot at maximum available BT, I_P = 800 kA, perhaps similar to shot 113546, 113531-5 (or good shot now after Li injection)
   - LSN or inside wall limited, helium L-mode, gap 4-5 cm
   - Modulate P_{RF} as for shot 112699 with $k_{||}$ = 14 m^{-1}
   - Choose one of the 5 beam conditions (sources, energy) as in Heidbrink/Ruskov exp.
   - All shots with 14 m^{-1} phasing

   Bring P_{RF} up to ~ 2 MW (maximum power not so important as reproducibility)
2. Test variation with beam energy, geometry
   - Obtain a shot with each of the 5 beam possibilities, all else fixed
   - Scan density, if practical, to follow up on Heidbrink's observation
3. Test variation with gap geometry/SOL parameters
   - Choose fixed beam geometry, energy, density based on 2)
   - Vary outer gap, inner gap, top and/or bottom gaps, looking for a change in the SOL density measured by reflectometer
   - This may be slower, due to the necessity of retuning every time the edge condition is successfully changed

Critical Diagnostics (same list as J. Hosea with a few more)

- Soft x-ray and Mirnov loops for stability
- E-parallel-to-B NPA, SSNPA for characterizing tails
- Neutrons for characterizing tails
- EFIT with high time resolution for W
- Thomson scattering for electrons
- Edge rotation diagnostic for edge heating
- Radiated power diagnostic
- Reflectometry for edge density and PDI
- Edge probe for PDI
- Gap RF probes for leakage
- RF probe(s) for edge RF field

Expected Results (with apologies to J. Hosea!)

- Heating efficiencies vs. variations in beam geometry, energy, and vs. variations in edge absorption (at fixed phasing, BT)
  - Core heating from EFIT W
  - Core electron heating from Thomson scattering
- Edge heating/power loss
  - Edge ion heating from edge rotation diagnostic
  - Edge electron heating from Thomson scattering
- Behavior of PDI characteristics and induced losses with field
- Plasma profiles , core and edge, to permit predictions of wave propagation and damping characteristics and of PDI produced losses
- Relative surface wave amplitude for comparison to surface power loss for the explored conditions
- Ceramic gap RF emission for the explored conditions

Planned Analysis

- Calculation of τ and ΔW for EFIT W to obtain percent P_{RF} absorbed in core
- Calculation of τ_e and ΔW_e for Thomson scattering W_e to obtain P_{RF} deposited on electrons
- Search for variations of efficiencies from the scans of beam parameters with variations from scans of edge parameters

Planned publication of results

- The results will be submitted for publication in our favorite journal, whatever that might happen to be at the time