MODELING OF NBI+HHFW IN NSTX

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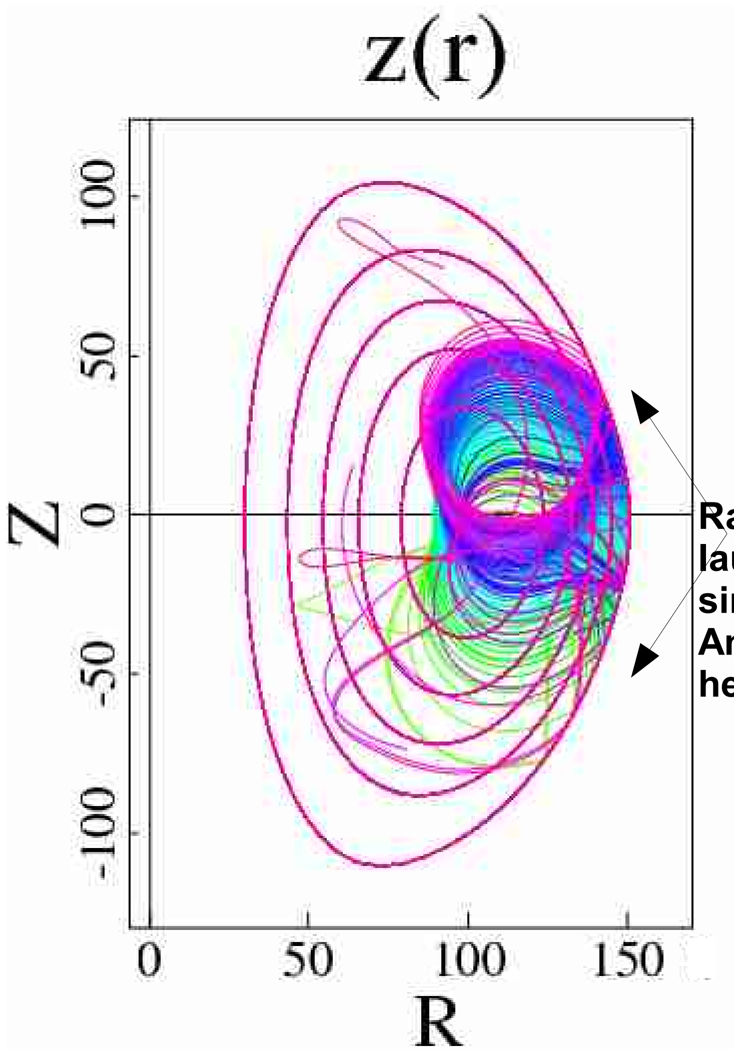
OUTLINE:

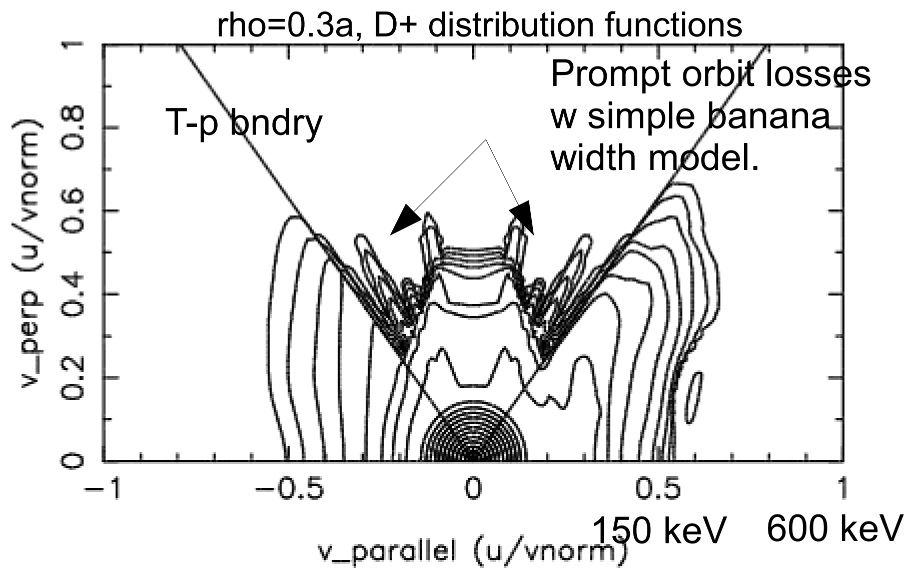
- **CQL3D + GENRAY (rays) gives estimate of HHFW absorption, including NBI, and provides nonthermal D^+ distributions for calculation of FIDA, NPA and dN_n/dt.**
- **CQL3D + AORSA (full wave code): more accurate rf, and indicates some spatial broadening.**
- **Deyong Liu/Heidbrink FIDA results indicate much broader FI profiles than derived from above calculations.**
- **Addition of 1st order orbit-width effects to CQL3D substantially broadens calculated FI profiles giving possible agreement with FIDA.**
- **AORSA+DC (Lorentz orbit diffusion calculator)+CQL3D gives greater accuracy for both orbits and HHFW induced diffusion.**
- **We are examining production of heating along field lines in front of antenna (LH and/Wave-Particle trapping?) to account for HHFW edge heating observations.**
- **Future work.**

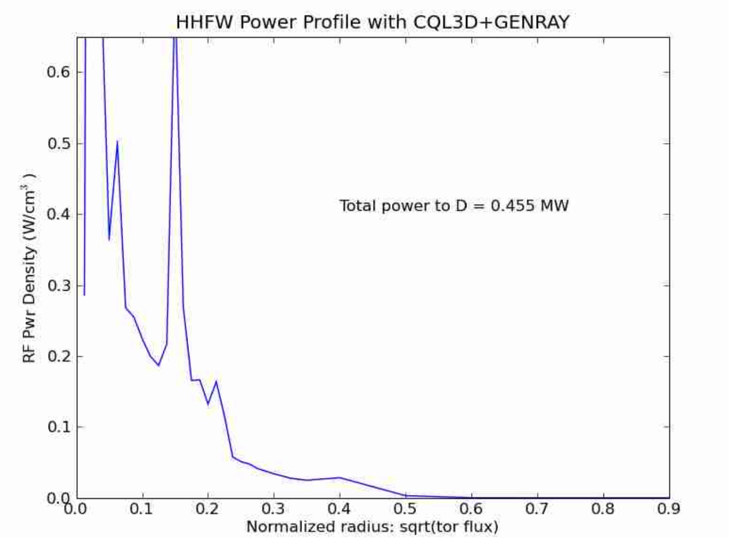
Fokker-Planck Analysis with CQL3D+GENRAY(rays)/NSTX #128739

(CQL3D presently has zero-orbit-width approximation)



Rays launched simulating Antenna height

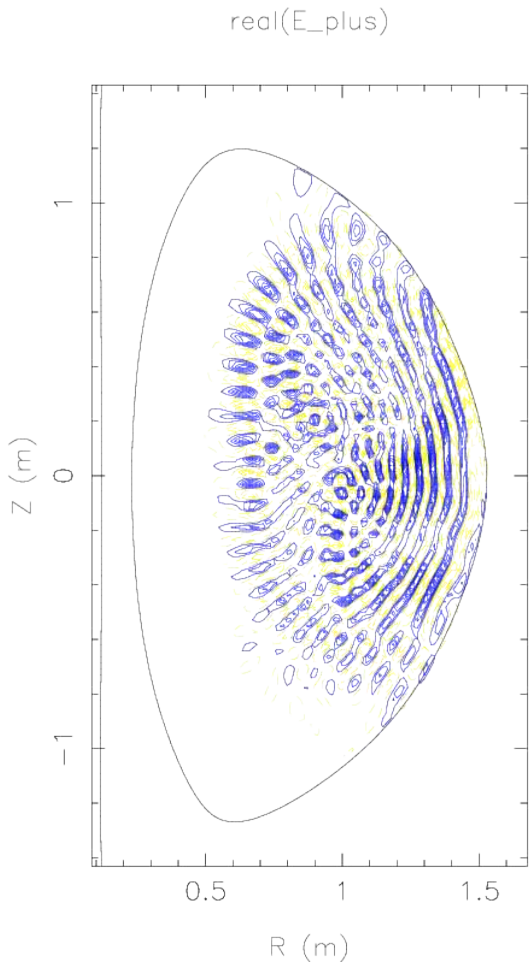




Fokker-Planck Analysis With CQL3D+AORSA(full wave)
(CQL3D also has zero-orbit-width approximation here)

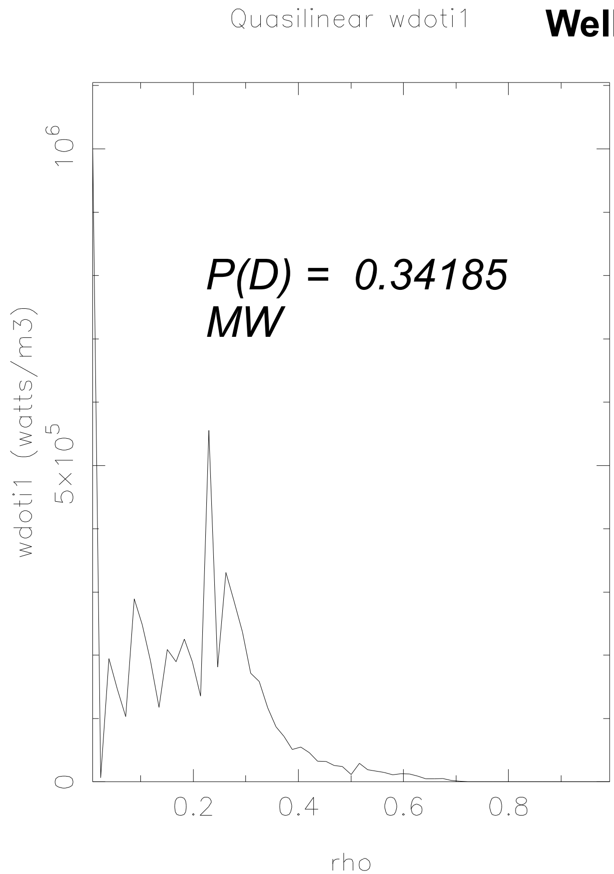
NSTX (Shot 128739.0300) power absorption (Jaeger)

AORSA field similar to GENRAY

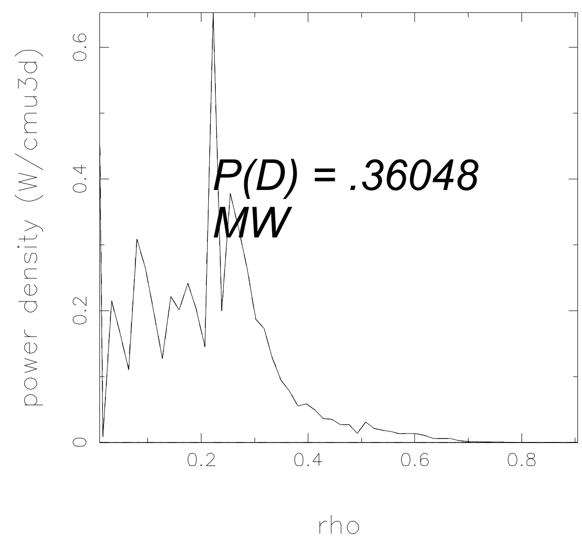


AORSA Pwr

Well Converged



CQL3D Pwr



Iterated between AORSA and CQL3D to Steady State ==> **Broader profile**
BUT NOT ENOUGH

FIDA Indicates Much Broader Fast Ion Radial Profile

Too Narrow FIDA from CQL3D with RF (within ~0.2a)

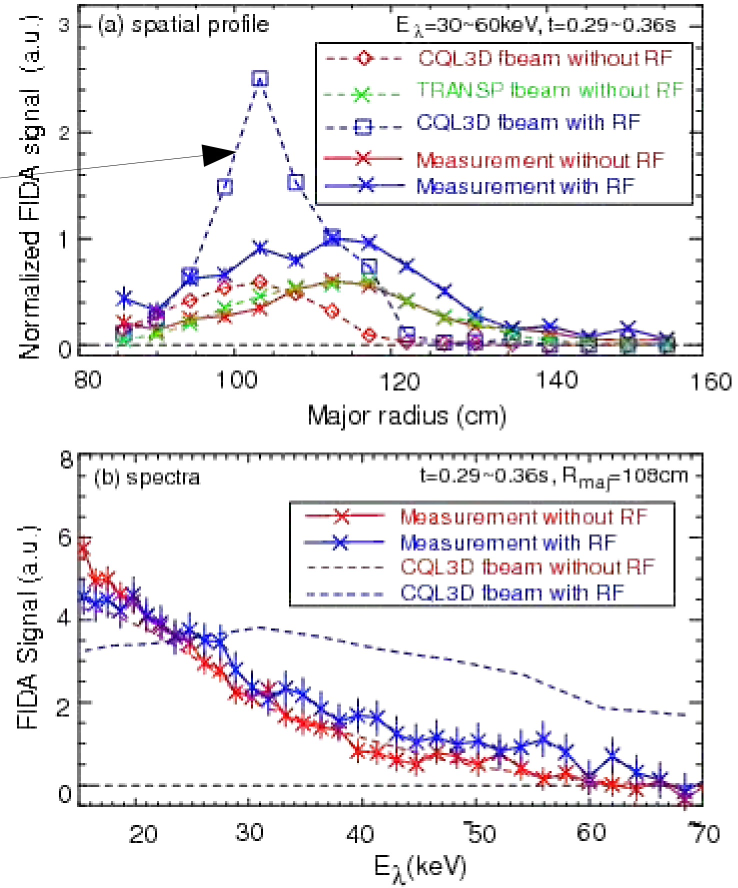
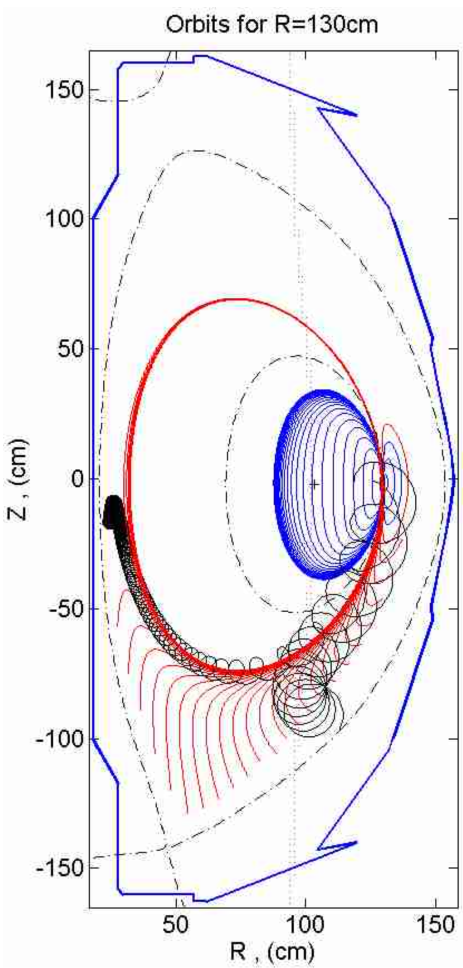


Figure 15: Comparison of (a) FIDA spatial profiles and (b) FIDA energy spectra of chord 11 with $R_{maj} = 108$ cm from measurements and simulations.

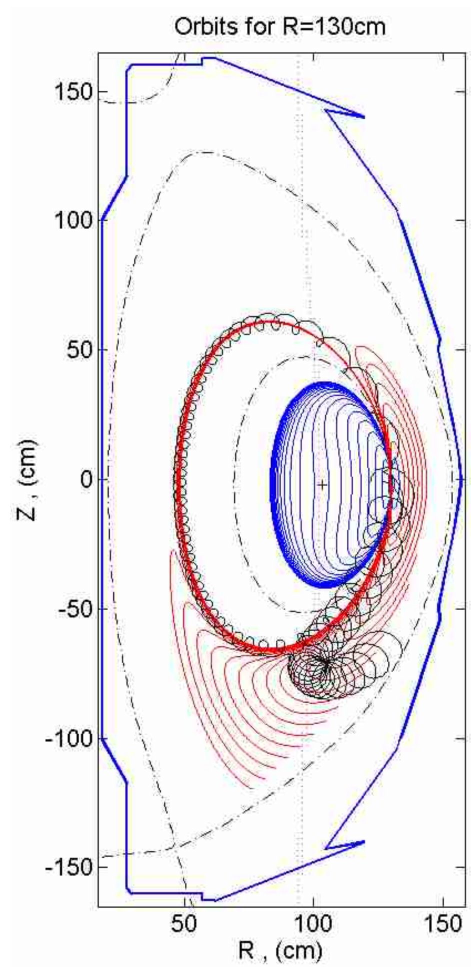
(Deyong Liu et al., submitted for publication)

Orbits are Large in NSTX, and Accurate Particle Modeling Requires that this be Accounted For

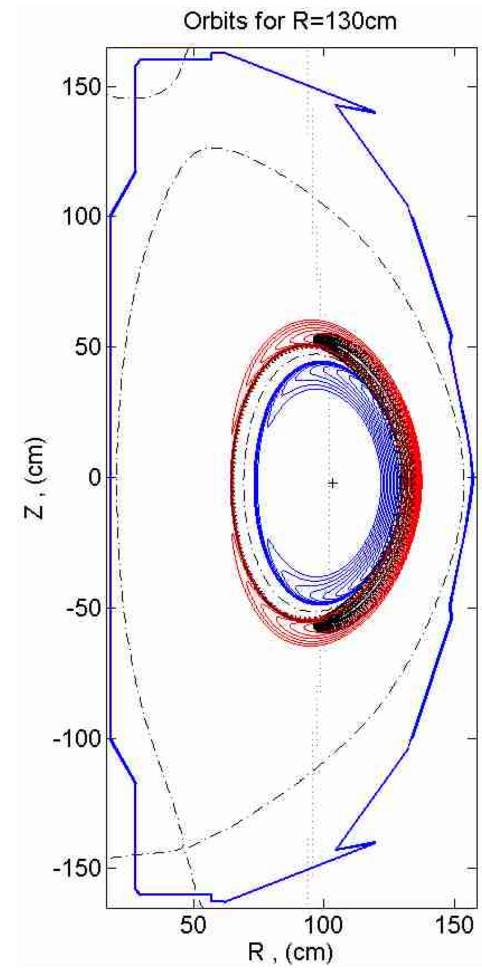
Deuterium ions are shown at 64 equi-spaced pitch angles, launched from mid-radius with full- and half-beam energy, and thermal energy.
NSTX shot 128739.00295, blue:co-orbits, red: counter-orbits
==> **Most counter-trapped orbits at full- and half-beam energy are lost.**



Beam energy, 65 keV



Half beam energy, 33.5 keV

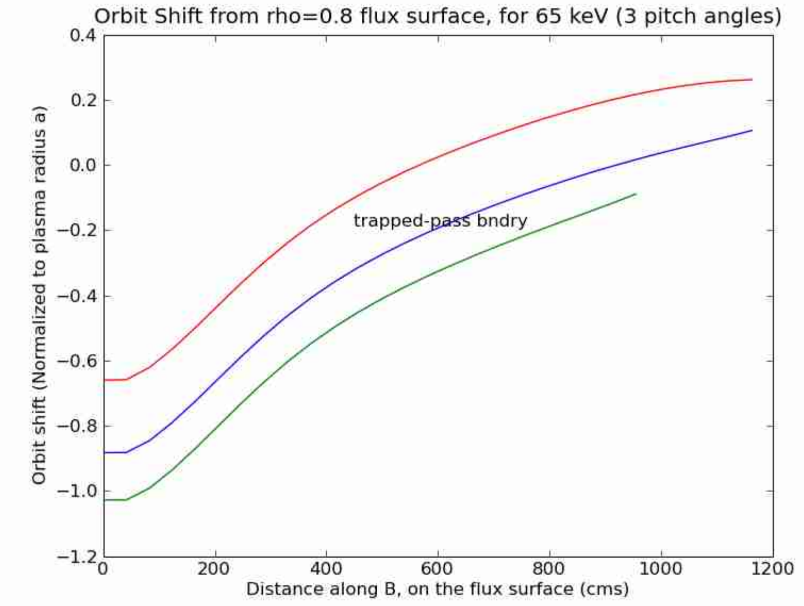


Thermal energy, 2 keV

First Order Orbit-Width Calculation Added to CQL3D

- A major inaccuracy in the present zero-orbit width calculation with CQL3D is that while ions hitting the wall are promptly lost (in an approximate manner), leaving few fast ions outside of ~0.3a, clearly there should be FIs out to near the plasma edge.
- We reinterpret distributions at each radius as representing particles with bounce-averaged posn at the that radius.
- The new calculation properly accounts for the fast ions out to the plasma edge, in terms of their densities as represented by particles with bounce-averaged radial position out out to 0.3a.
- For each R,Z-point and v_par,v_perp, the approx.| (1st order) orbit shift **to** the corresponding bounce-averaged radial position is obtained.
- This data is to be used by the FIDA analysis referring each R,Z along the view chord to the correct distribution function.
- AORSA also needs to be adjusted for self-consistent damping on orbit-shifted distributions.

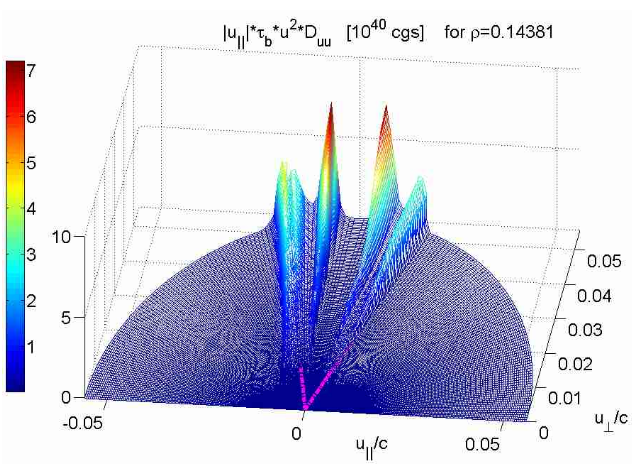
Example of orbit-shift calculation, at rho=0.8a flux surface, for pitch angles near the t-p boundary.



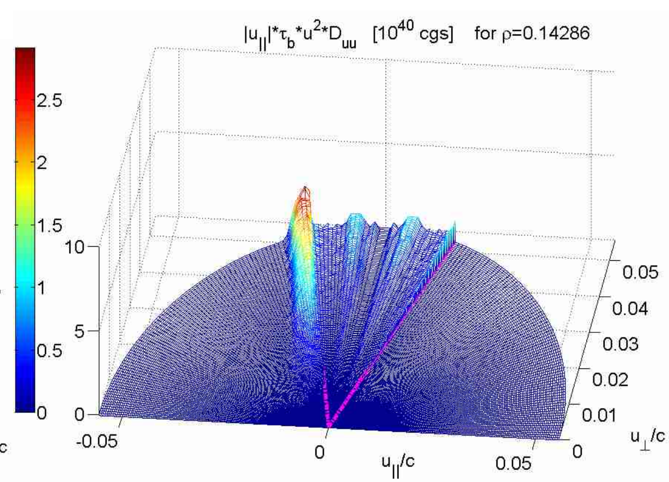
AORSA + CQL3D + DC

- DC (originally motivated by NSTX) calculates RF Diffusion Coefficients by integrating the Lorentz force equation for ion orbits in the combined equilibrium and AORSA EM fields.
- Ions are launched at set of radii, v_par,v_perp, gyroangle, and toroidal angle and followed for one (or more) poloidal rotations
  ==> Bounce-avg'd diffusion coeffs, with finite gyro-and drift-width, correlations, and multiple cyclotron resonance crossing per gyro-period (FIs in NSTX). Prompt losses.
- The DC coeffs are read into CQL3D ==>time-dependent evolution of D+ (using multiple cycles of AORSA-DC-CQL3D).
- This work has shown some results of simpler C-Mod case, and is in progress for NSTX:

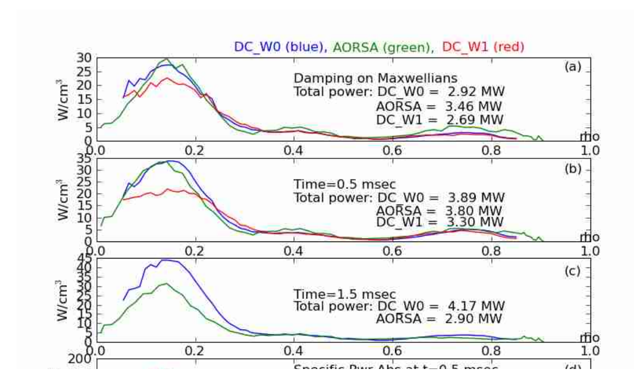
DC(1 poloidal turn, correlated)



AORSA (uncorrelated)



Comparison of radial pwr deposition, DC (drift subtracted), DC(full orbit), AORSA (0 orbit-width)



==> Additional radial spreading of absorption; correlations don't change absorption until anisotropy develops.

LH Propagation from the Antenna into SOL, at <2.6e10/cm**3

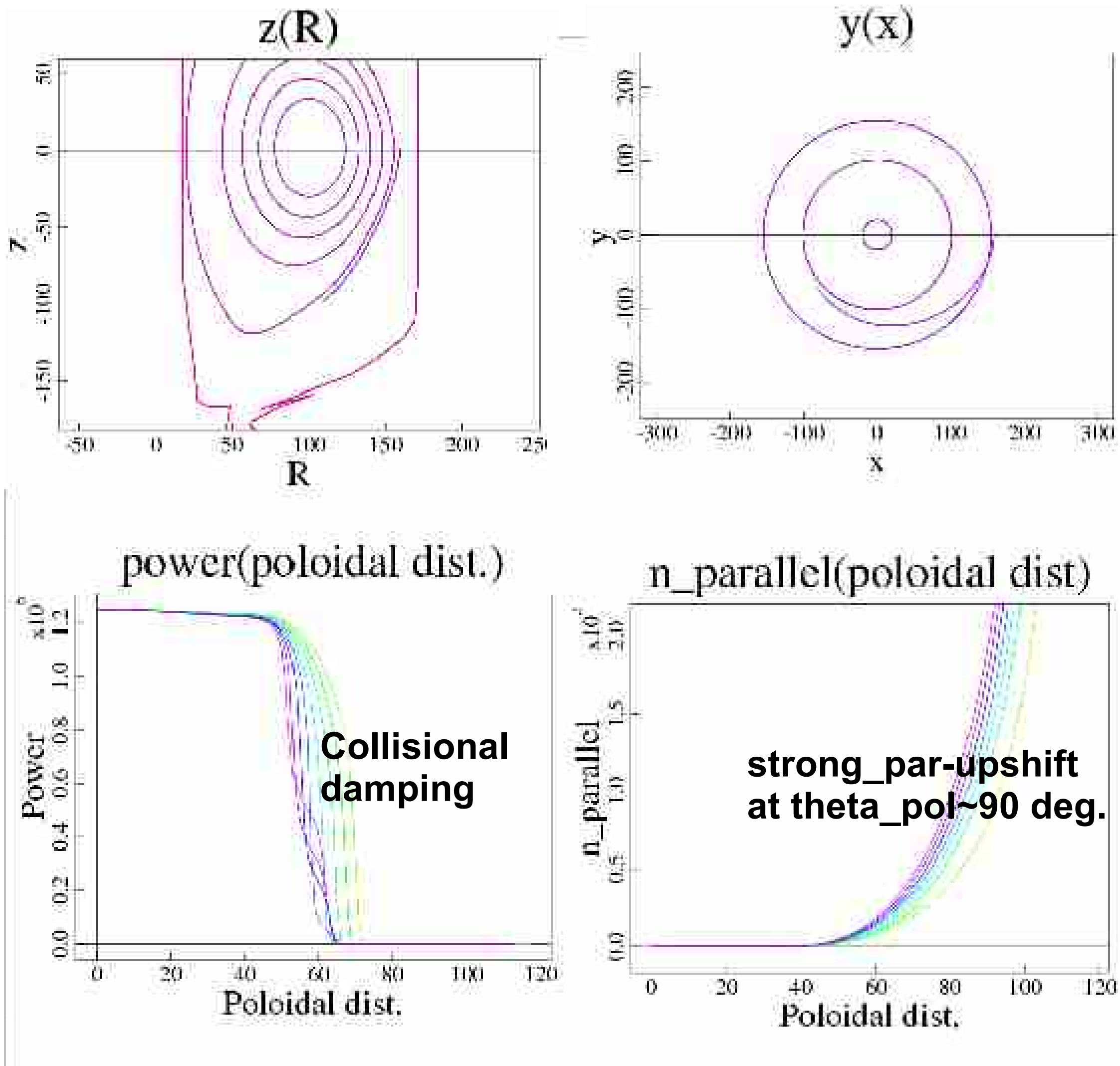


Figure 2. Lower hybrid rays launched in NSTX SOL. This 30 MHz ray energy propagates along the magnetic field lines at density 4x10[10] cm-3, and is collisionally damped within distance 60 cms measured in the poloidal plane as n_par becomes large/parallel group velocity small. This distance is quite independent of Te in 1-10 eV range due to the rapid onset of n_par-upshift. Damping is collisional/Landau at the lower/higher edge Te.

LH edge propagation provides means for field line heating, if the density is low enough.

Additional SOL Effects:

(1) Ponderomotive force pushes plasma back (Brf~3 guass gives Erf=90 keV/m, but Epar2 > 2nT if Epar =5 keV/m.**

(2) LH filamentation at similar field strength (seen in Gegelman UCLA experiment).

(3) Single paricle acceleration in near fields:
-trapping of bulk at 30 keV/m
-ponderomotive exclusion in parallel dirn ==> stochastic heating.

FUTURE WORK

- First order orbit-shifts will be implemented in analysis of CQL3D distributions for FIDA (Liu, Heidbrink, Harvey).

- First order orbit-shifts in rf codes (e.g., AORSA) are required, to account self-consistently for the FI profile.

- Calculation of edge fields in front of antenna (work by/with Dave Smithe, Tech-X) to obtain fields near antenna in presence of plasma.

- Further consideration of (1)NL effects on density, (2)possible LH launch, and (3)wave-trapping/heating of edge electrons.

- DC-AORSA-CQL3D iteration for distribution functions accounting for correlations and multiple harmonic interactions with Fis.

- New finite-orbit extension of CQL3D is planned to begin in FY2010, with NSTX as major application.

- Applications of CQL3D/DC and rf codes to NSTX, with PPPL collaborators.