Non-Thermal Wave-Particle Modeling for NSTX
(CompX, in collaboration with PPPL, MIT, ORNL)

Outline:

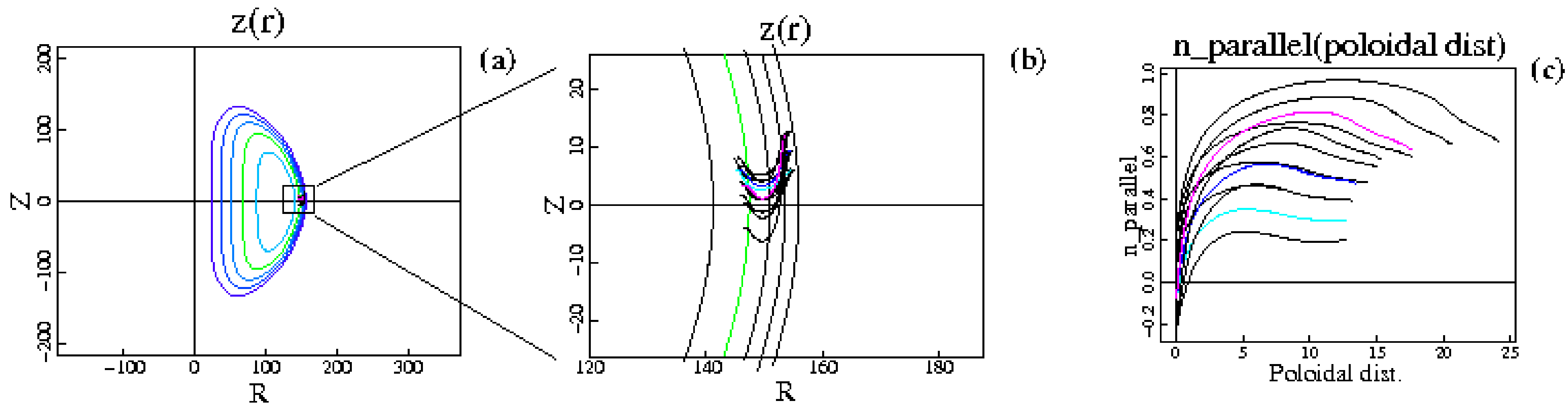
- Past modeling examined non-thermal electron distribution effects of EBW heating and current drive:
  - -EBWCD in 5, 20 and 40% beta NSTX model discharges (Taylor, Harvey, et al, PoP '04)
  - -Synergy of EBWCD and BSCD (Harvey and Taylor, PoP '05)
  - -Non-thermal EBW emission from model discharges (Harvey, Smirnov, Taylor, et al, EC-14 '06)
- HHFW simulations of time-dependent non-thermal ion distributions (Rosenberg et al, PoP, '04)

This presents context for:

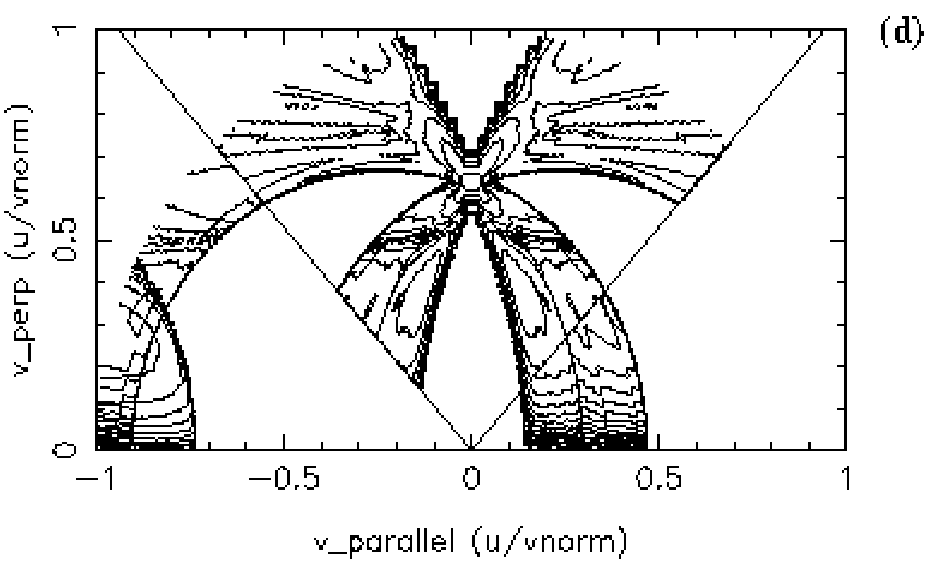
- Present NSTX efforts

- Future efforts

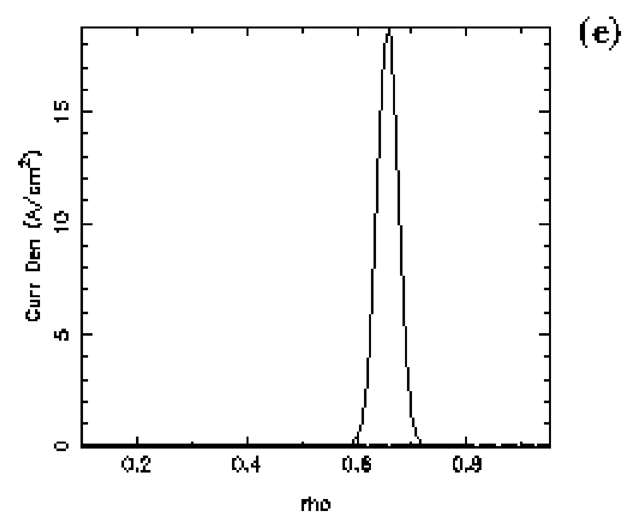
GENRAY/CQL3D Modeling of EBWCD



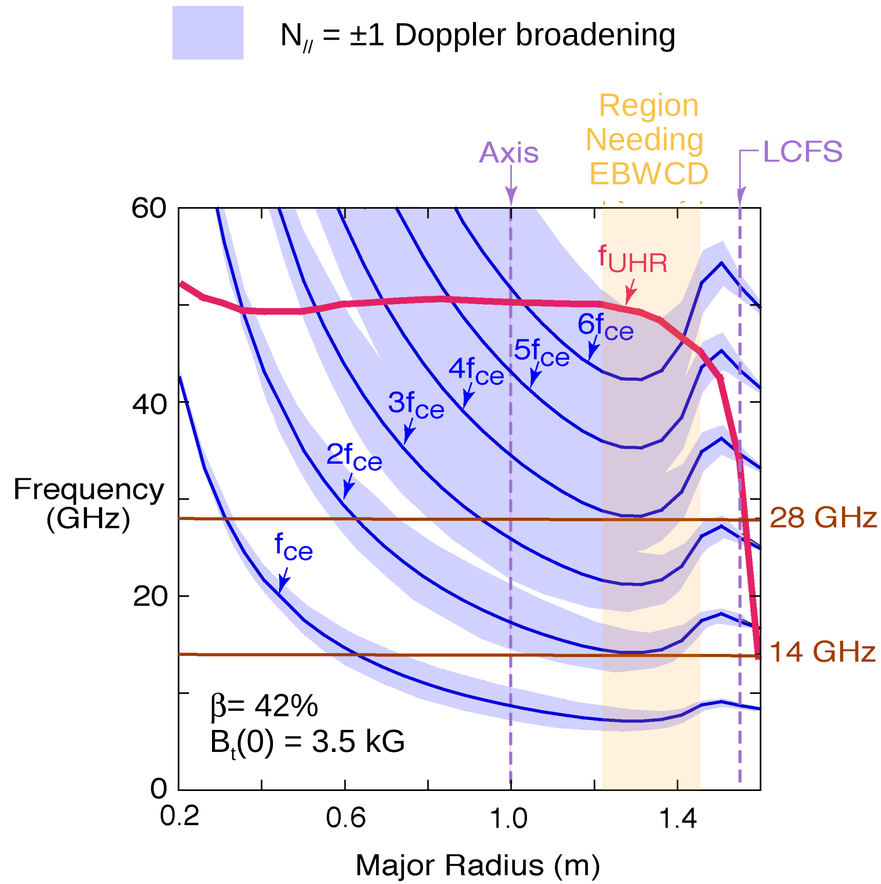
RF QL Diff Coeff ==> Peaked near TP Bndry

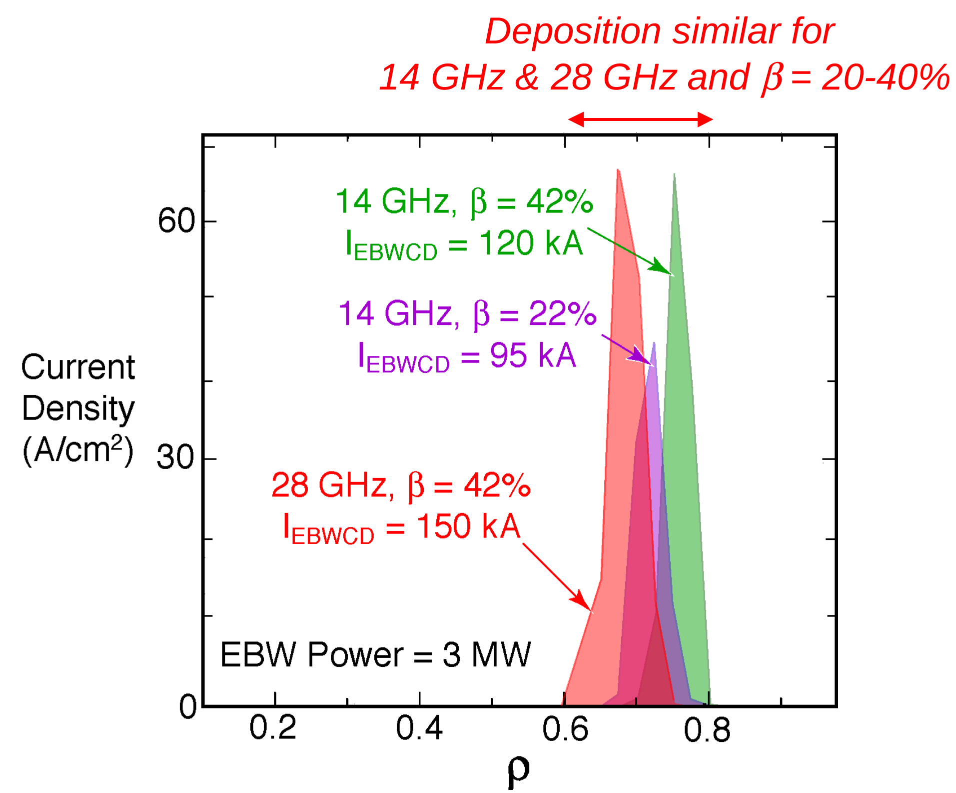


Radial Profile of EBW Ohkawa CD



Can Access Region Requiring EBWCD to Stabilize High β Non-Inductive Plasma





- GENRAY ray tracing & CQL3D Fokker-Planck codes model NSTX EBWCD

G. Taylor, et al ., Phys. Plasmas ***11****, 4733 (2004)*
R.W. Harvey & G. Taylor, Phys. Plasmas ***12****, 051509 (2005)*

→ Need efficient coupling of RF power to EBWs; assess oblique O-X-B coupling by measuring B-X-O emission (EBE)

Electron Bernstein Emission Due to Nonthermal Distributions in NSTX

- **GENRAY calculates electron Bernstein wave emission (EBWE) from thermal or non-thermal distributions (and is also an all frequencies ray tracing code).**
- **Emission and absorption are calculated at each point along an EBW ray, and the radiation transport eqn (below) is back-solved to the detector.**
- **A hot plasma dispersion relation (Forest) and a relativistic calculation of the emission and absorption is used.**
- **The BXO (Bernstein-X-O mode conversion) emission window is found with a shooting algorithm to obtain the central ray angles for a given receiver (antenna) position, such that $|n_{\|}|=(1+\omega/\omega_{ce})^{-1/2}$, giving 100% transmission (Kopecky et al., J. Pl. Phys., 1969).**

Radiation Transport Equation for radiation intensity, I, per (vol freq ster):

$$n_r^2 \hat{\mathbf{s}} . \nabla (n_r^{-2} I) = j - \alpha I$$

$n_r =$ Ray refractive index

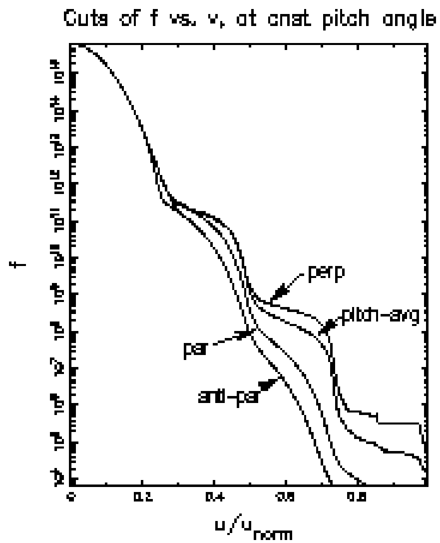
$\hat{\mathbf{s}} =$ Ray direction (parallel to group velocity_

$j =$ Radiated power per (volume • radian freq • steradian) [See underneath pg]

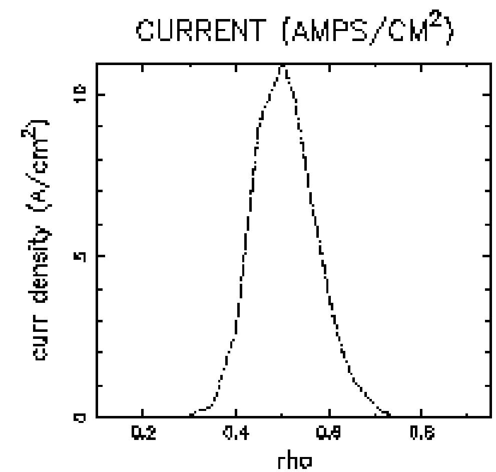
$\alpha =$ Absorption coefficient [See underneath pg]

Comparison of EBWE from Thermal and Non–Thermal NSTX Shot (113544) [With next few slides]

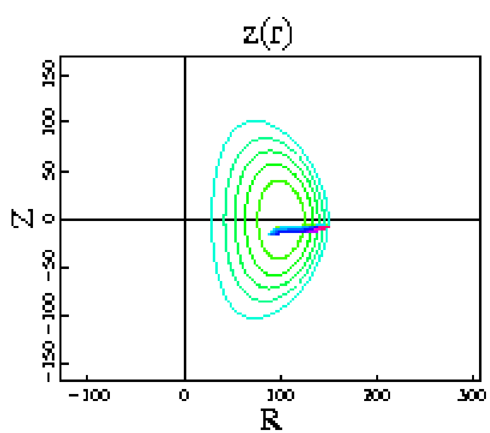
Non–Thermal Dististributions used for calcs vs rho (here = 0.59)

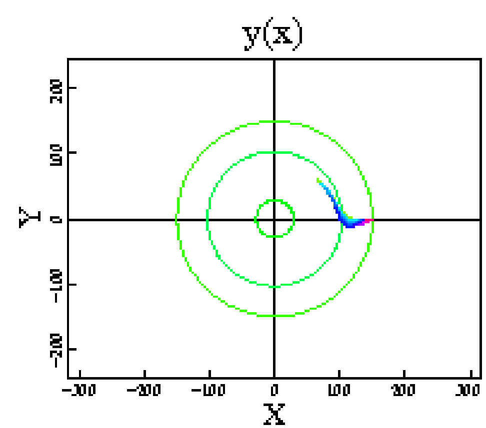


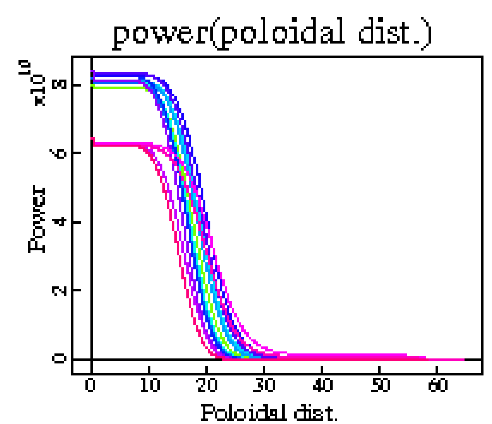
Radial variation of EBWCD vs rho. 1MW EBW, 47 kA.



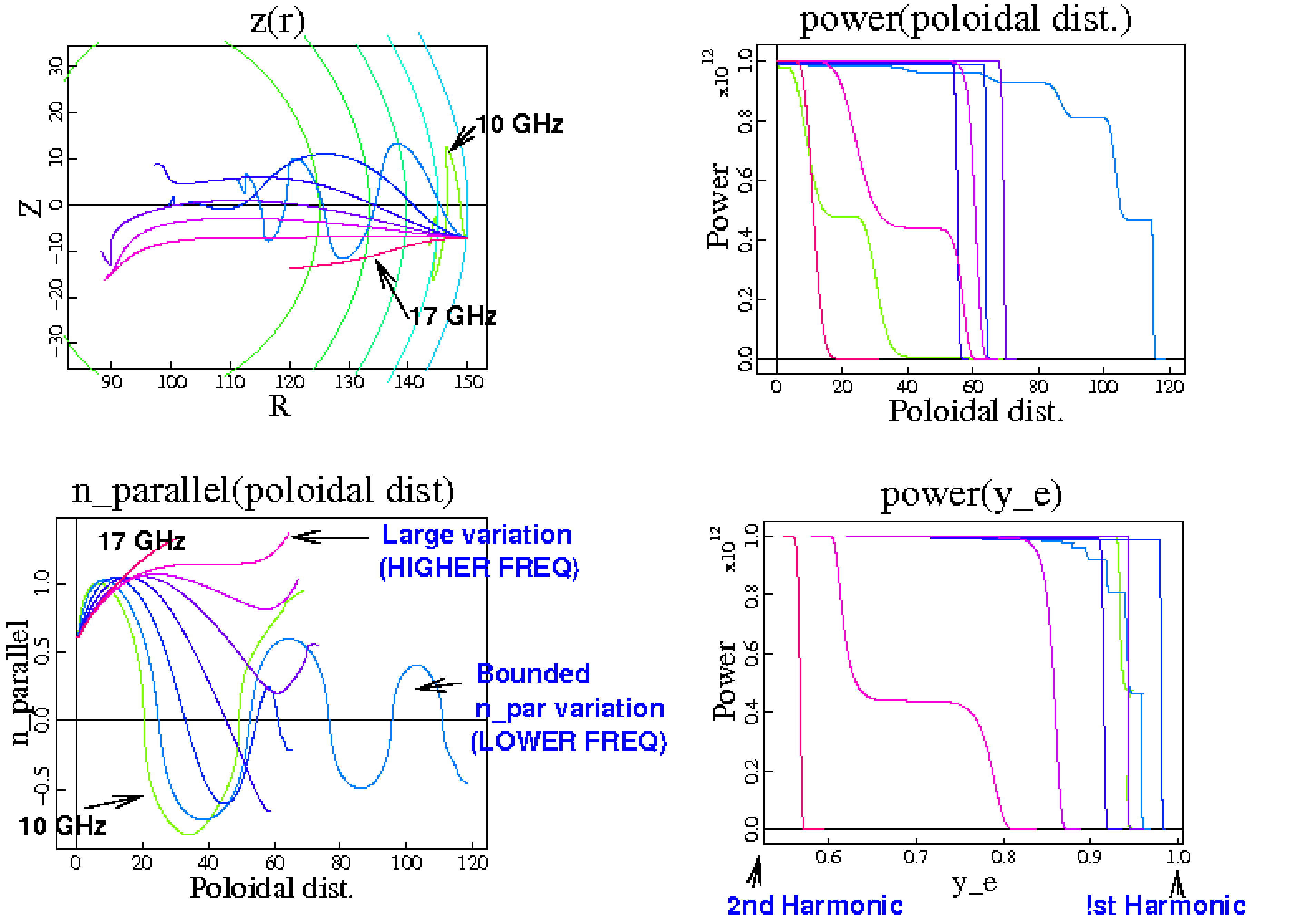
Good penetration of 16.5GHz, EBW with OXB launch







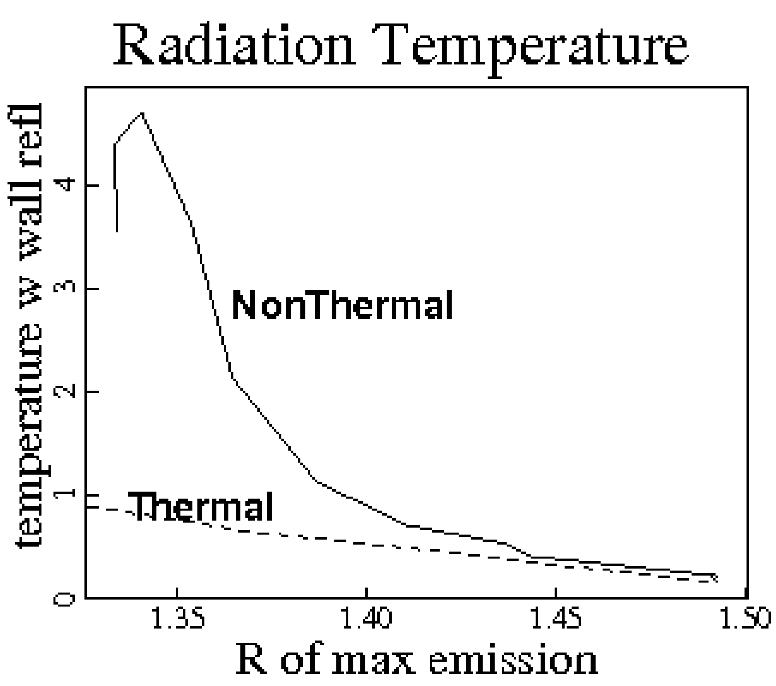
Ray Characteristics in 1st–2nd Harm Range (10–17GHz)



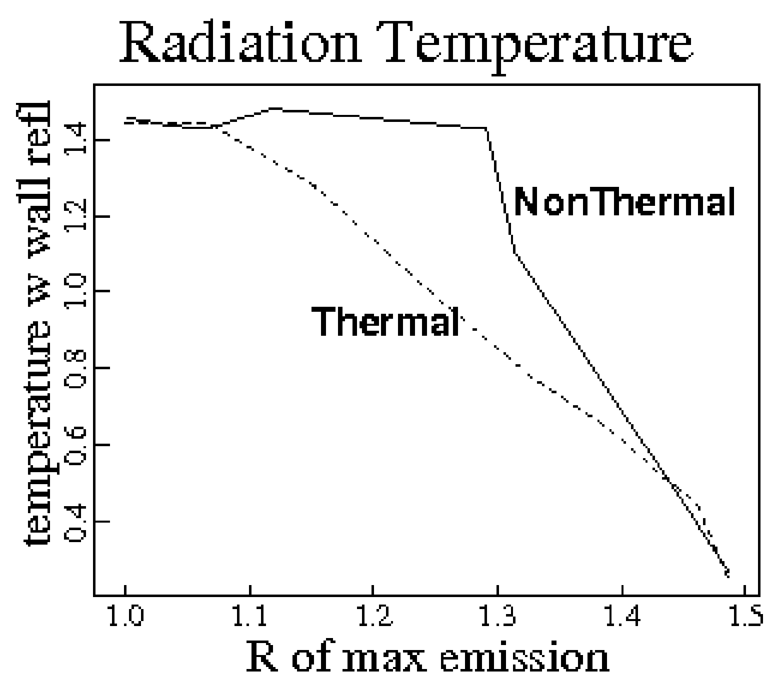
High Freq Radiation Gives Strong Nonthermal Trad, whereas, Low Freq Gives Near Thermal Trad (Low Beta case)

- This result depends on whether there is large n_par (high freq), or small (low freq)

High Frequency

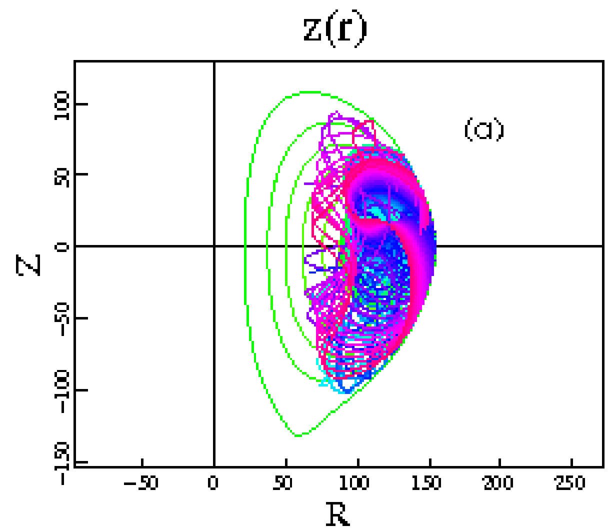


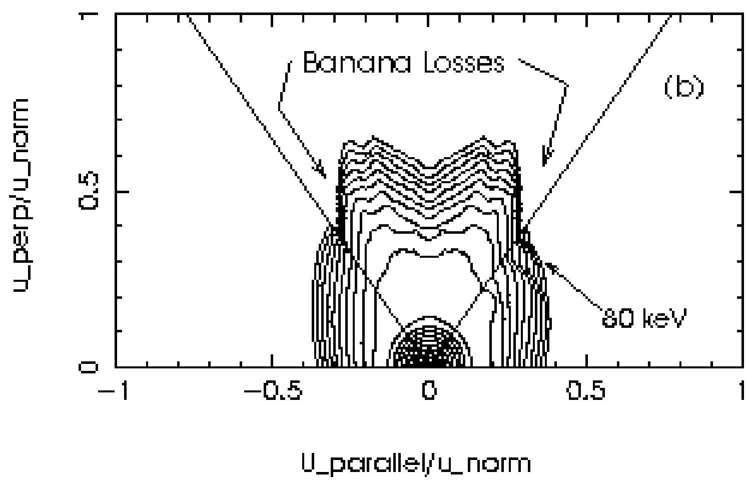
Low Frequency

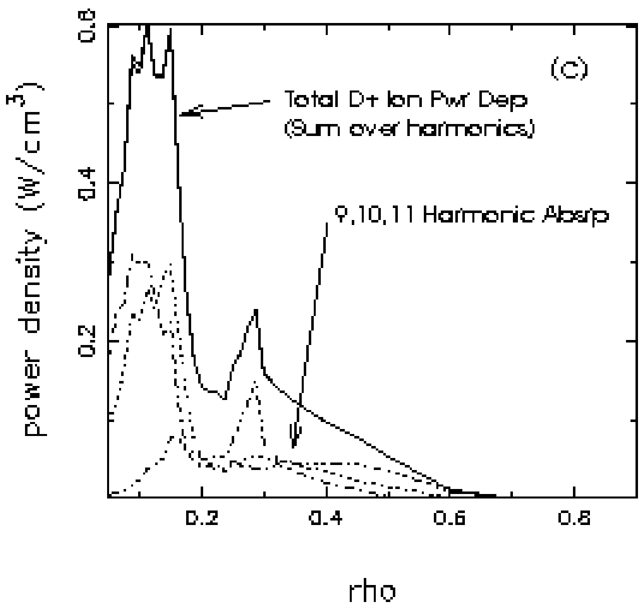


==> EBWE a flexible means to examine both thermal and non-thermal distributions

HHFW Modeling with GENRAY and CQL3D







New Capabilities:

•NPA (Vincent Tang, MIT work. Compared well with expt.

•Approx Neocl transport model

•More harmonics

•Coupled to AORSA for RF (as alternate to GENRAY)

Future Work:

•Multi-ion QL diffusion

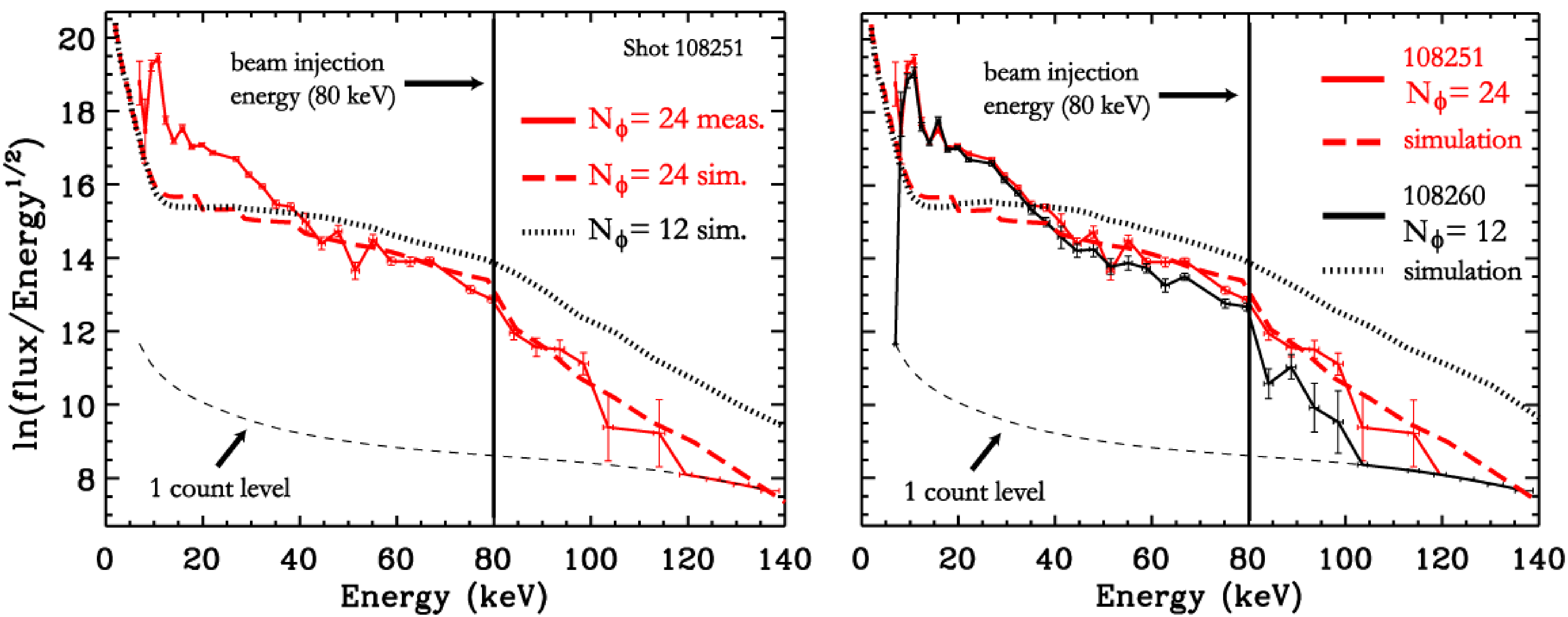
•Improved t-dependent, radial diffusion

•Finite gc orbit width effects

•FIDA synthetic diagnostic (Heidbrink)

Good agreement between NPA observations and CQL3D simulation is obtained at high $k_{||}$, but NPA is much less than simulation at low $k_{||}$ (Rosenberg)

NSTX



- No $k_{||}$ evolution measurement available
- Edge-coupling effects, theory breakdown at low $k_{||}$?
  - To be further investigated
- **Recent work in DIII-D shows importance of radial transport and possible importance for small H-fraction in the D-plasma.**

Present, Future, and Ongoing (separately funded) work

- **Present NSTX effort is directed towards:**
  - -improvements in GENRAY OXB coupling of EBW calculation (w collisional damping)
  - -improvements in GENRAY FW and LH ray launching (also prop'n outside separatrix)
  - -EBW coupling with AORSA1D (with Jaeger and Ram)
  - -EBWCD in ARIES-ST (Nelson-Melby et al., submitted to PPCF '07)
  - -Benchmarking of EBW ray tracing and FP calculation vs Culham codes (w Saveliev)
- **Future NSTX effort:**
  - -Radial transport effects on EBWCD
  - -HHFW/NBI modeling of nonthermal ions, including radial transport (impt in DIII-D)
  - -Improvement of(/contributions to) synthetic diagnostics (NPA, FIDA, Ion loss,....)
  - -Coupling GENRAY and CQL3D to TRANSP
- **Additional ongoing work of use for NSTX modeling:**
  - -Finite banana effects (under separate Theory contract)
  - -RF-SciDAC coupling of CQL3D to TORIC, for faster full-wave analysis (than AORSA)
  - -SWIM (RF and MHD) project, coupling transport, RF and MHD codes