EBW-Bootstrap Current Synergy in NSTX

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- EBW presents near ideal conditions for enhanced BSCD by RF induced pitch angle scattering, particularly in Spherical Tori
- A kinetic calculation of bootstrap current combining collisions and EBW QL diffusion is given below, using a simplified BS model in the CQL3D Fokker-Planck code
- The model is validated against standard BS results
- Application is made to an NSTX 40% beta equilibrium

Bootstrap Current Model, and Validation

Simple model of bootstrap based on physical picture:

- At each radius there is a net magnetization current: co-current producing particles have average position one-half banana width inwards, whereas counter current producing particles have average position shifted outwards ==> (due to density gradients)

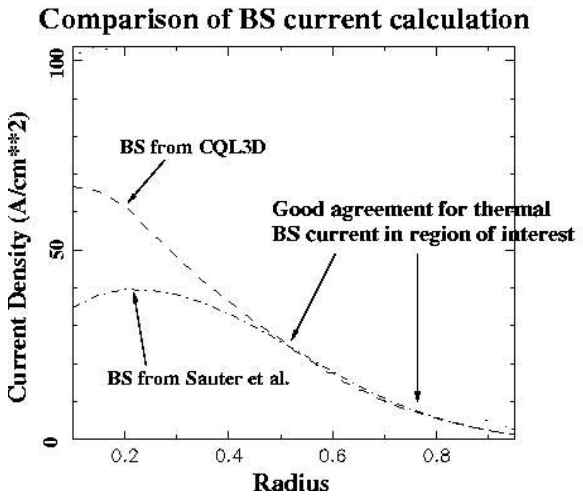
$$j_{banana} = -ev_{\|}(\Delta_{banana}\frac{dn_{trap}}{d\rho}) = -\frac{\varepsilon^{3/2}}{B_{pol}}\frac{dp}{d\rho}$$

- Detrapping of the plasma particles (collisions, rf) ==> source in transitting particles, amplifying j_{banana} to give bootstrap current

$$j_{bootstrap} = -\frac{\varepsilon^{1/2}}{B_{pol}}\frac{dp}{d\rho}$$

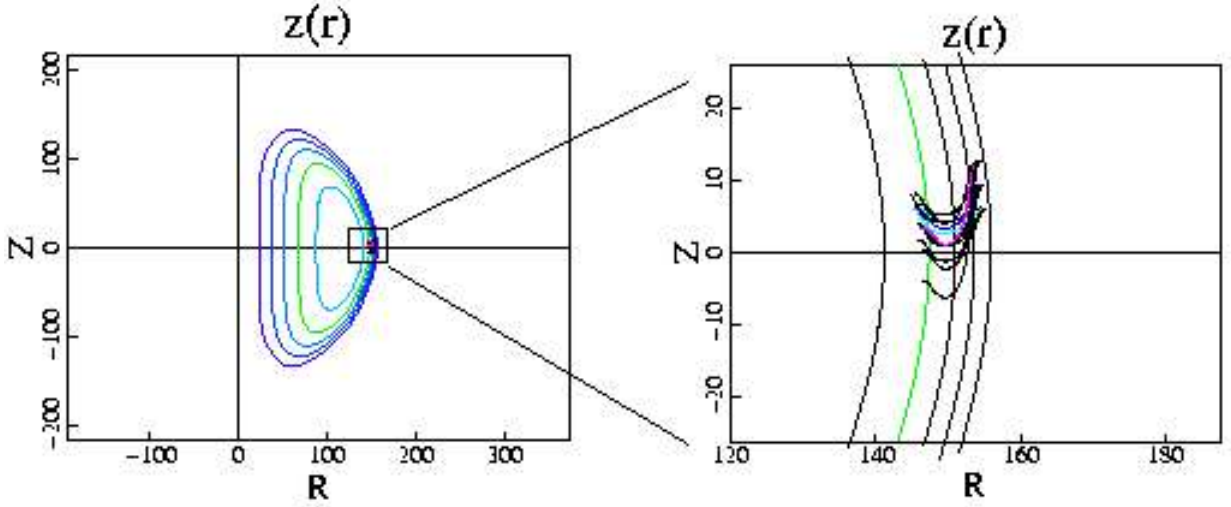
- The CQL3D Fokker-Planck code (otherwise zero-banana) implements this model by connecting co/counter-current passing particles to trapped particles displaced 1/2 banana inwards/outwards.

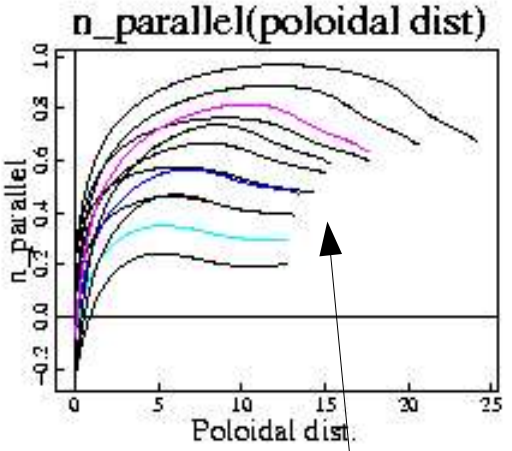
Validation of simplified kinetic model of BS current:



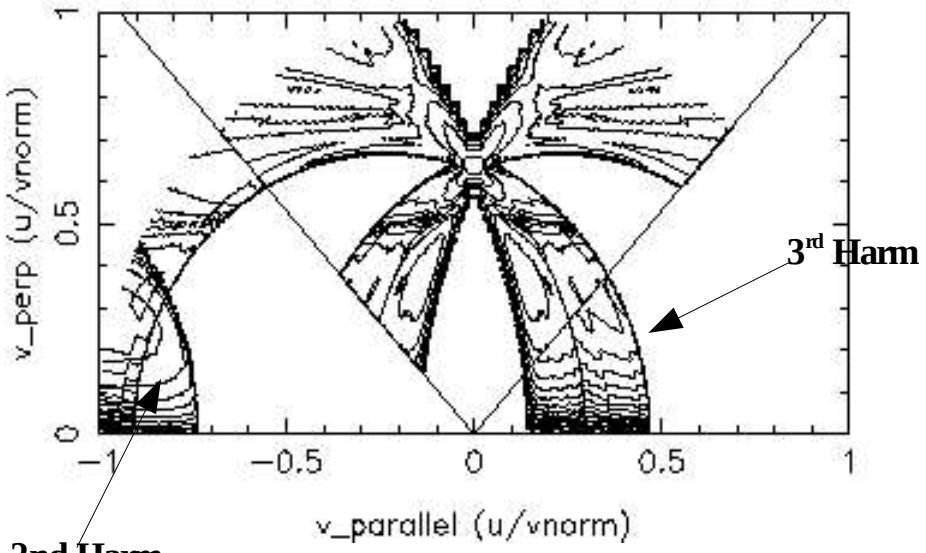
CQL3D and accurate Sauter (PoP,'99) results agree well over outer half of ST. (Inside eps=0.3, Westerhof (CPC, '96) found refinements again giving good agreement.)

EBW Rays in NSTX and Resulting QL Diffusion



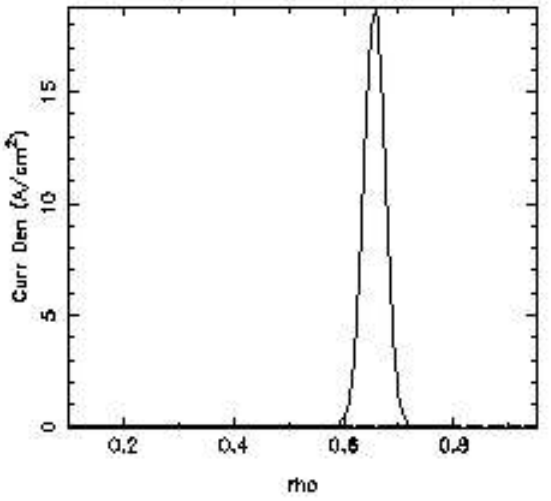


3rd Harm absorp



3rd Harm

2nd Harm

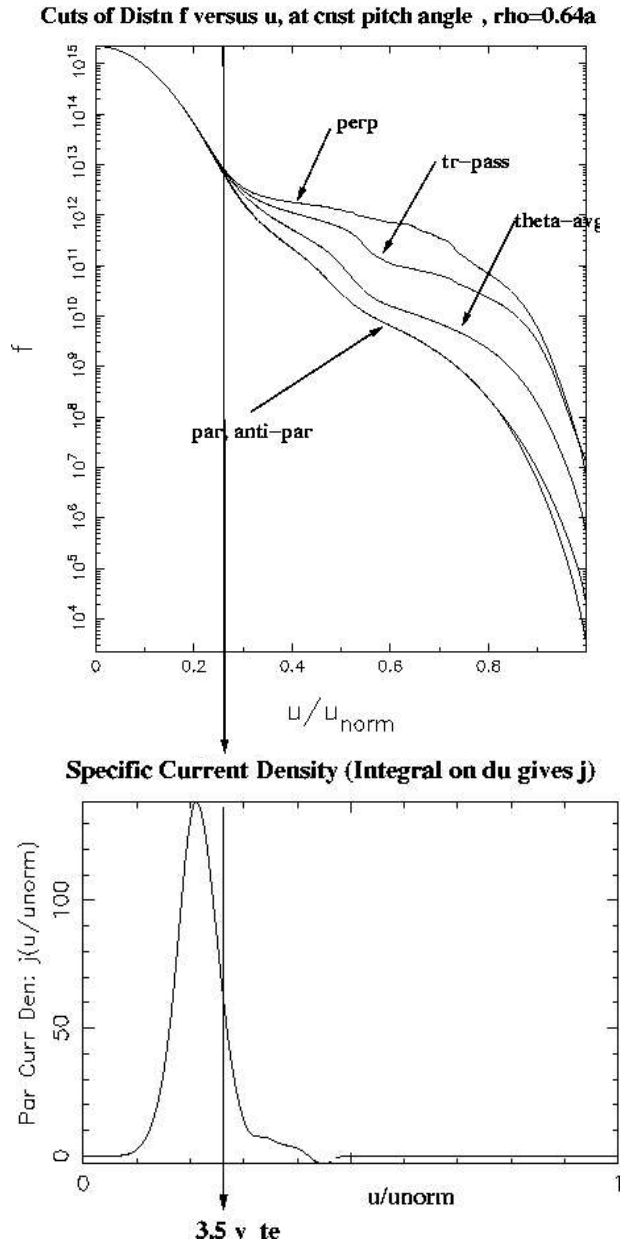


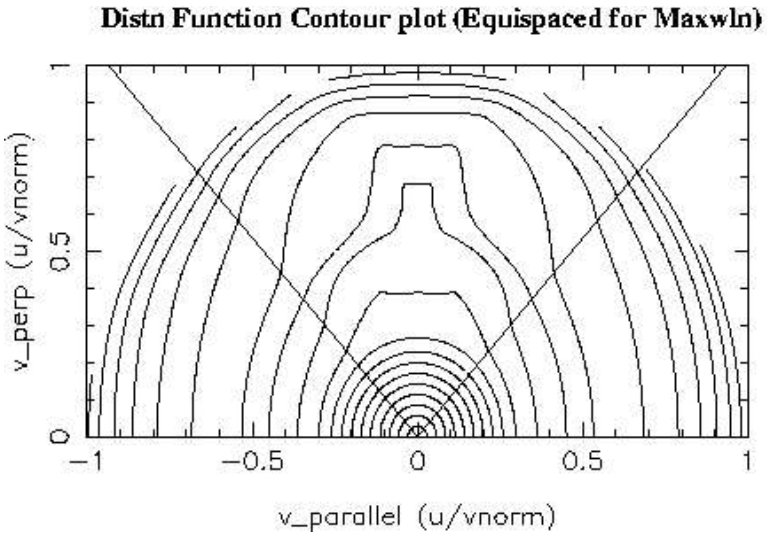
Neg elec current ==>

Positive current j due to the Ohkawa CD effect.

COMPX

EBWCD, 1MW, Bootstrap Model Off

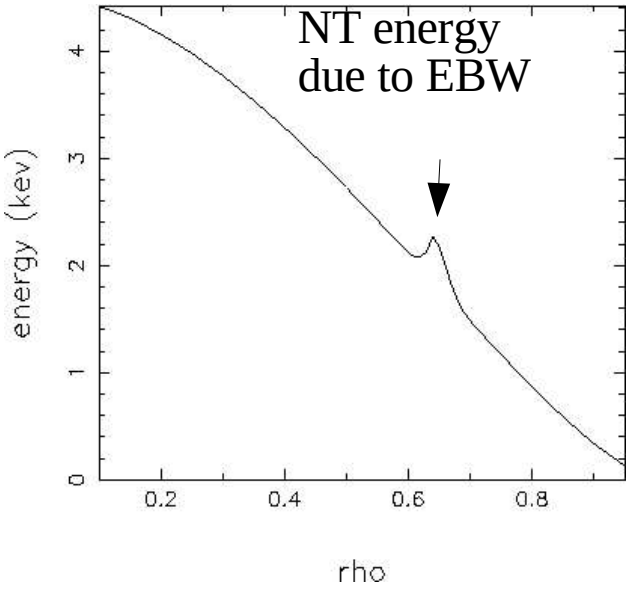


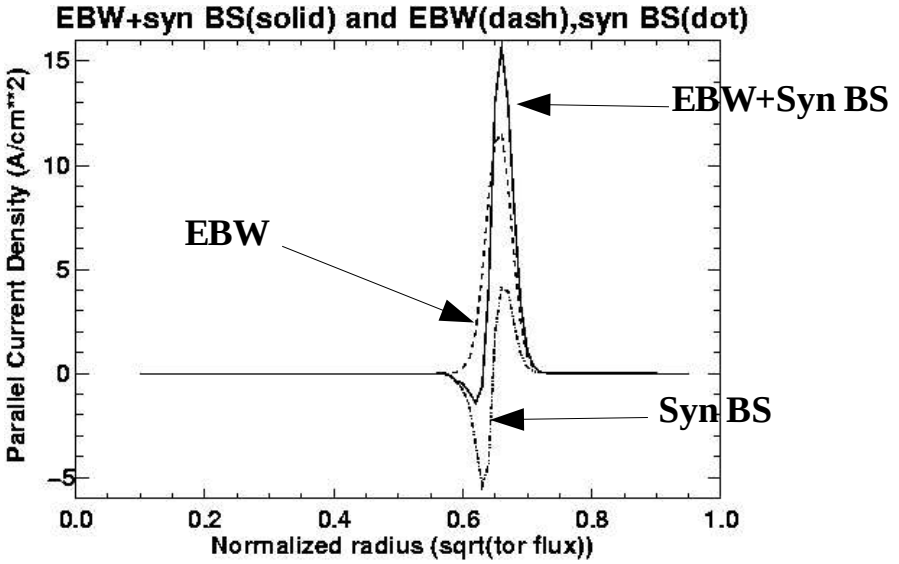


- Ninety percent of the EBWCD is in the near-Maxwellian region at v < 3.5 v_te.
- Collisions dominate the RF.
- No substantial EBW Synergy at this RF level (and plasma density).

1MW EBW, Bootstrap Model On

Plasma energy vs radius





- Enhanced RF pitch angle scattering would yield BS current which is symmetric about the RF heating region.
- A this 1 MW level, Syn BS current is anti-symmetric, therefore due to the locally enhanced plasma pressure.
- (At 4 MW, 10% symmetric increase in net Syn BS current is obtained.)

Summary of Co-Current Cases

Table 1: EBWCD supporting equilibrium current

Case	RF Power (MW)	Net Current (kA)	Comment
BS only	-	496.106	
RF only, no BS	0.1	4.141	0.59-0.72a, peak@0.64
RF+BS	0.1	500.079	RF peak: 0.64a
RF+Synergy BS	0.1	3.97	(RF+BS)-(BS only), -4.2% RF
RF only	1.0	34.790	RF peak: 0.64a
RF+BS	1.0	530.370	RF peak: 0.64a
RF+Synergy BS	1.0	34.26	(RF+BS)-(BS only), -1.5%
RF only	4.0	100.95	
RF+BS	4.0	608.23	
RF+Synergy BS	4.0	112.12	(RF+BS)-(BS), 11% RF

Summary of Counter-Current Cases

Table 1: EBWCD counter to equilibrium current

Case	RF Power (MW)	Net Current (kA)	Comment
BS only	-	496.106	
RF only, no BS	0.1	-4.157	0.59-0.72a, peak@0.64
RF+BS	0.1	491.786	RF peak: 0.64a
RF+Synergy BS	0.1	-4.320	(RF+BS)-(BS only), +4% RF
RF only	1.0	-34.887	RF peak: 0.64a
RF+BS	1.0	460.743	RF peak: 0.64a
RF+Synergy BS	1.0	-35.363	(RF+BS)-(BS only), +1.4%
RF only	4.0	-100.968	
RF+BS	4.0	405.128	
RF+Synergy BS	4.0	-90.978	(RF+BS)-(BS only), -9.0%

Summary of Balanced-Injection Cases

Table 1: Symmetric wave spectra in co-/counter-current direction

Case	RF Power (MW)	Net Current (kA)	Comment
BS only	-	496.106	
RF only, no BS	0.1	-0.009	Good cancellation
RF+BS	0.1	495.932	
RF+Synergy BS	0.1	-0.373	(RF+BS)-(BS only), small syn
RF only	1.0	-0.077	
RF+BS	1.0	495.382	
RF+Synergy BS	1.0	-2.581	(RF+BS)-(BS), 7.4% SS RF
RF only	4.0	0.200	
RF+BS	4.0	506.583	
RF+Synergy BS	4.0	10.48	(RF+BS)-(BS), 10.4% SS RF

Conclusions

- A 40% beta NSTX discharge has been investigated computationally for evidence of BSCD due to EBW enhanced pitch angle scattering.
- The effect of RF pitch angle scattering on BS current is small (< 10%), for up to 4 MW of EBW power.
- When there is a localized enhancement of plasma pressure due to EBW heating, anti-symmetric BS will be excited. But this depends on heat transport.
- **POSTSCRIPT:** The EBWCD reported here is Ohkawa CD. In principle[Fisch, RMJ(1987); Harvey&Dendy, PF(1992)], the enhanced trapping gives, in the neoclassical transport picture, a particle pinch and a compensating BSCD due to the modified n_e-profile. (But particle transport is not well understood.)