

# Progress in EBW Current Drive Research Towards Enabling Sustained High $\beta$ , Solenoid-Free Operation on NSTX

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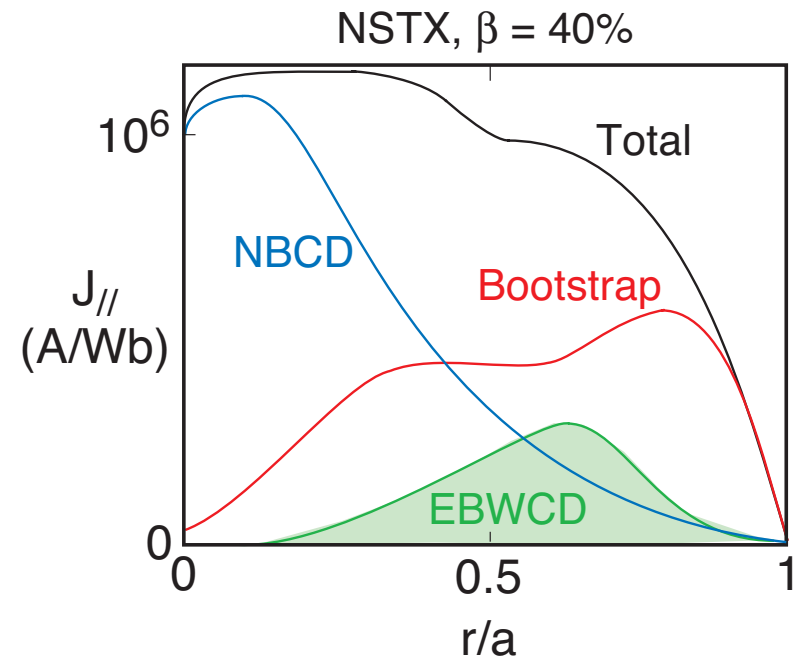
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# EBWCD Can Provide Critical Off-Axis Current to Sustain High $\beta$ Plasmas in NSTX

- $\sim 100$  kA of off-axis CD needed to sustain  $\beta \sim 40\%$  in NSTX
- EBWCD NTM stabilization also possible, but more challenging than ECCD to implement
- EBWCD & heating can assist plasma startup
- EBWCD research on NSTX has focused on EBWCD modeling & coupling studies via EBW emission

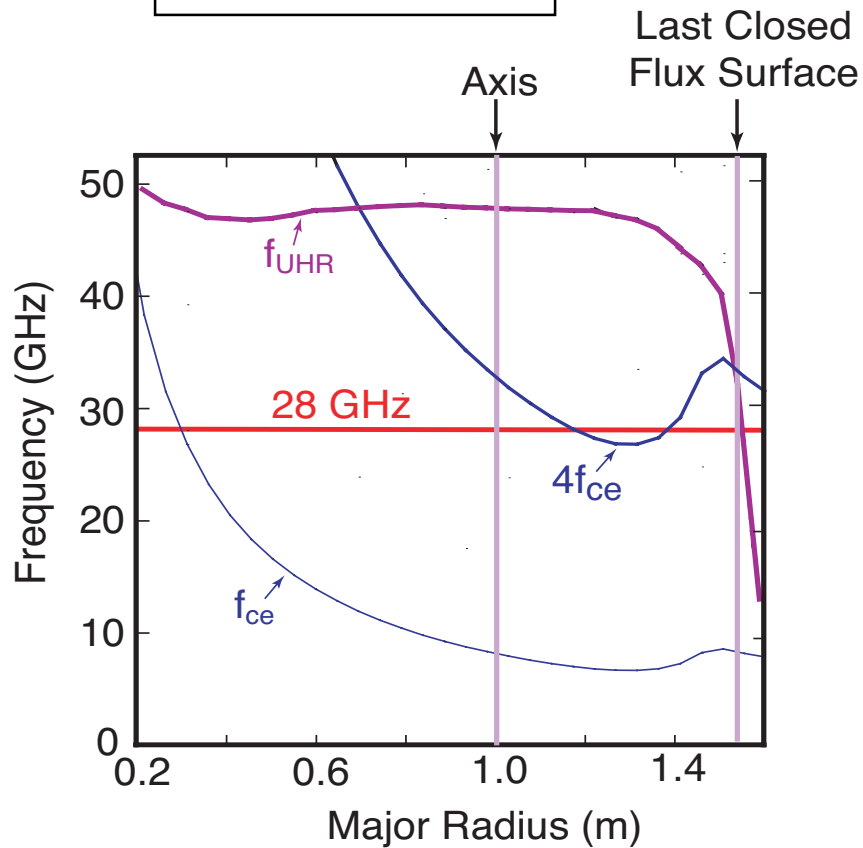


Charles Kessel (PPPL)  
Tokamak Simulation Code

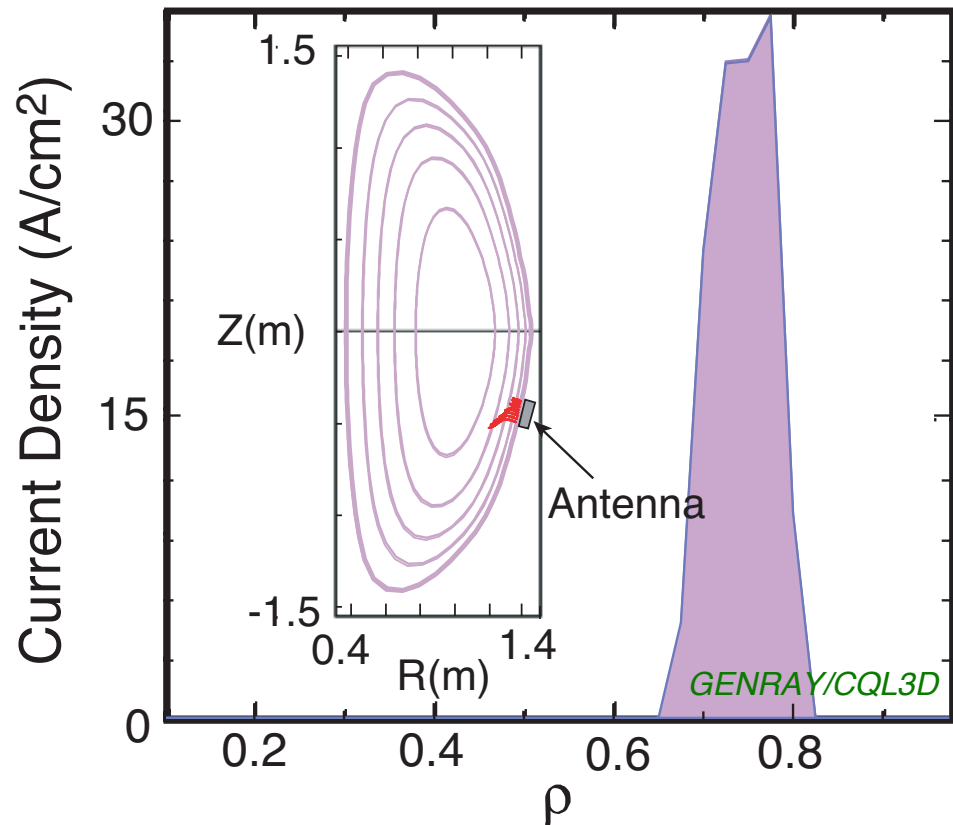


# Modeling Predicts 28 GHz EBWs Drive Efficient Off-Axis Ohkawa Current in NSTX Plasmas

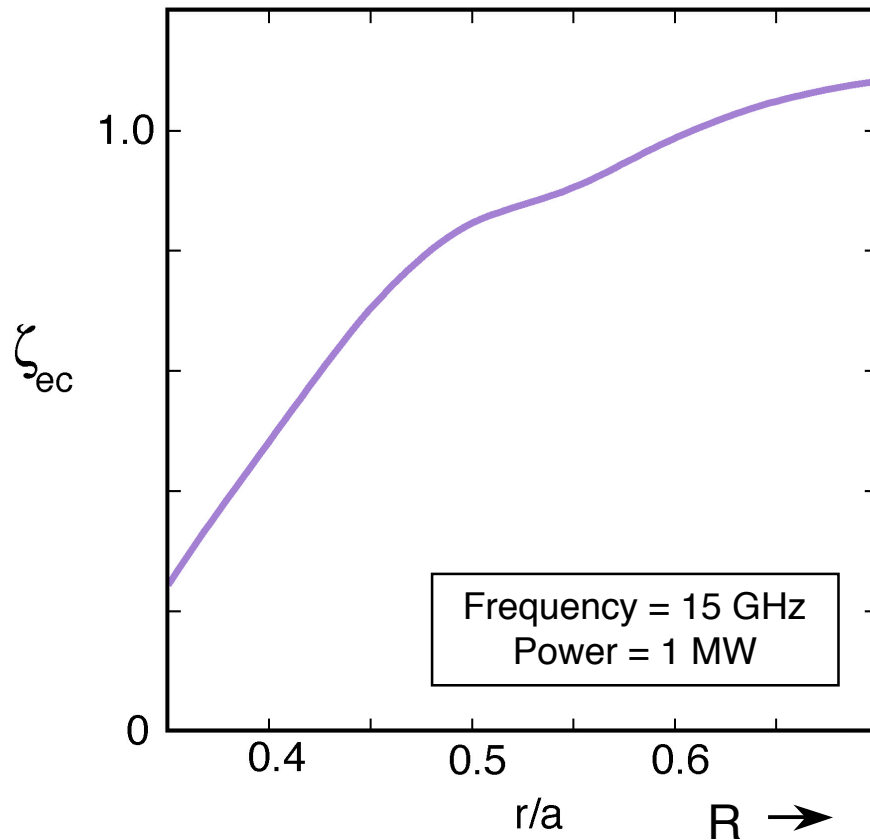
NSTX,  $\beta = 40\%$



Frequency = 28 GHz  
 EBW Power = 3 MW  
 Total Driven Current = 135 kA



# Normalized Ohkawa EBWCD Efficiency ( $\zeta_{ec}$ ) Increases with $r/a$ on Low Field Side of Axis

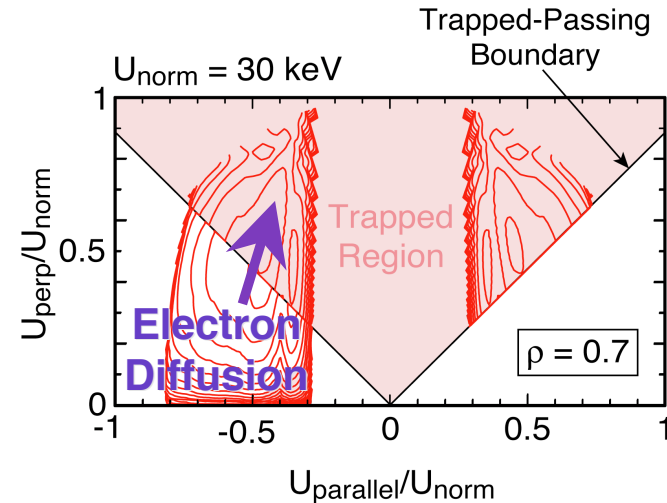


$$\zeta_{ec} = \frac{3.27 \times I_p(\text{A}) \times R(\text{m}) \times n_e (10^{19}\text{m}^{-3})}{T_e(\text{keV}) \times P(\text{W})}$$

[C.C. Petty, AIP Proc. 595, 275 (2001)]

[G. Taylor, et al., Phys. Plasmas 11, 4733 (2004)]

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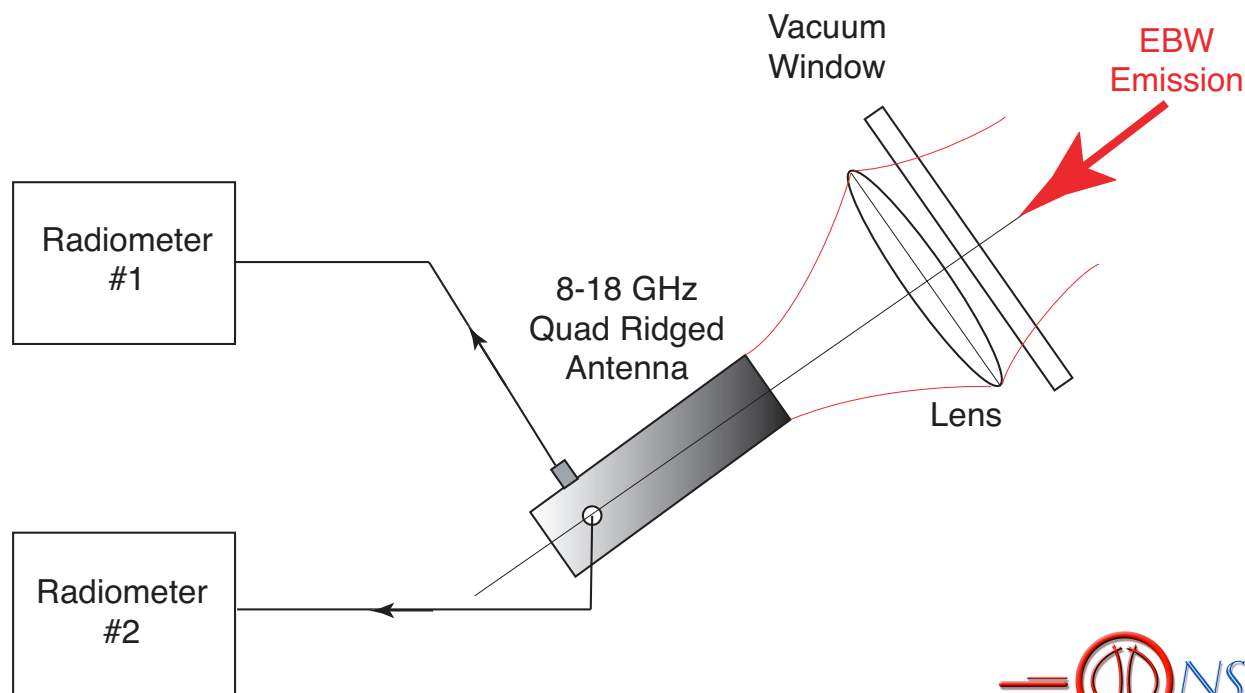


- Strong diffusion near trapped-passing boundary enables efficient Ohkawa EBWCD
- EBWCD-Bootstrap current synergy provides only  $\sim 10\%$  enhancement at  $P_{\text{EBW}} \sim 4 \text{ MW}$
- Plan to investigate effect of trapped particle pinch on EBWCD



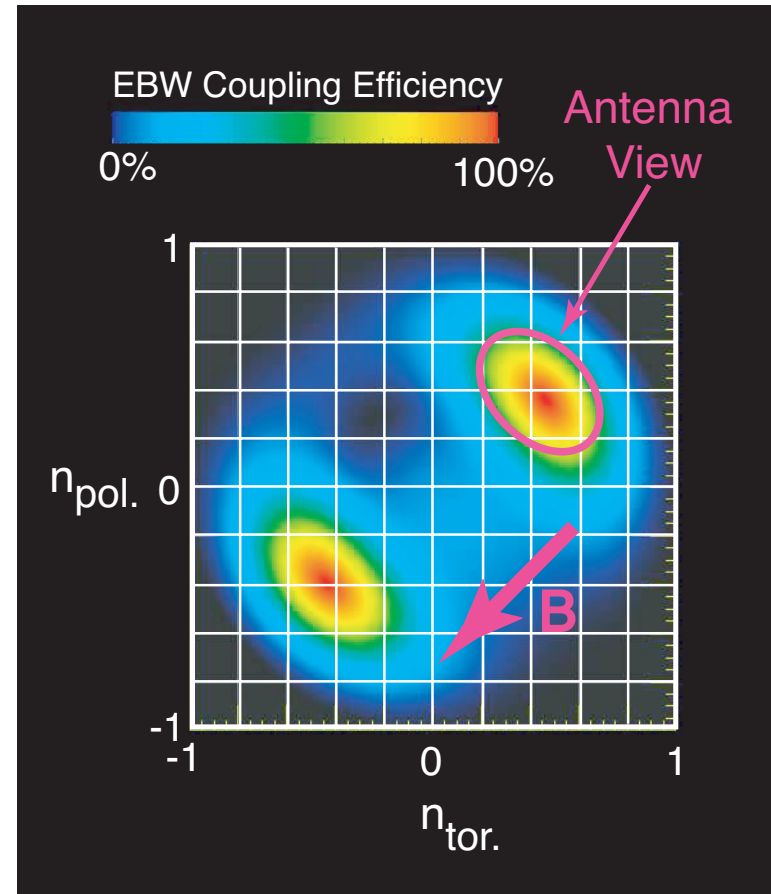
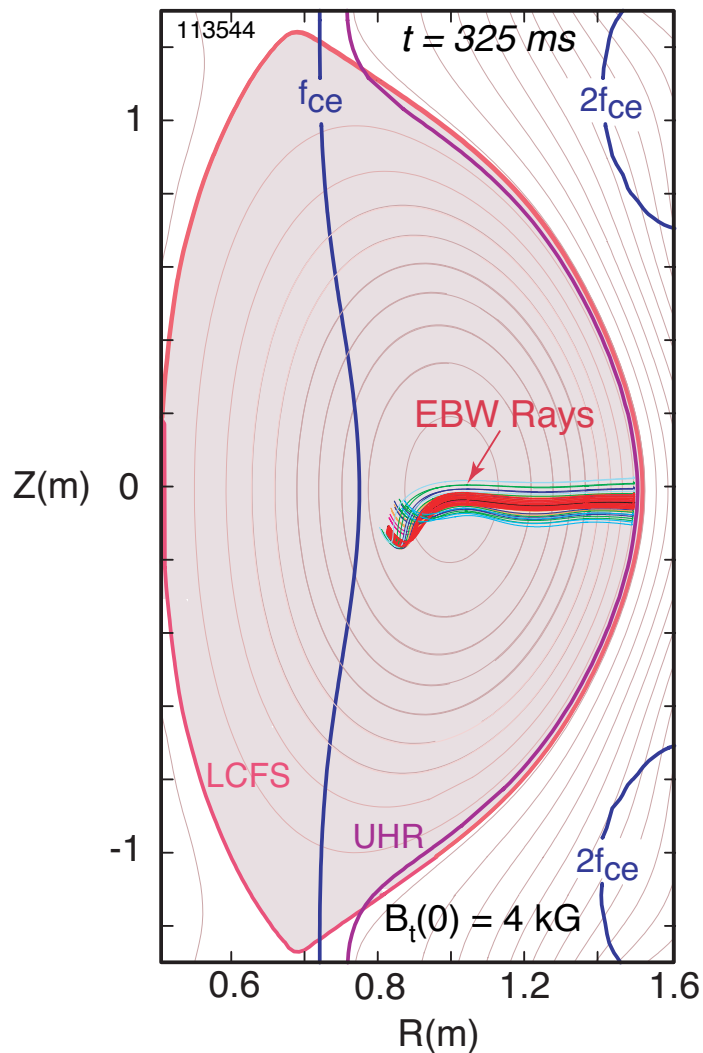
# NSTX Obliquely Viewing “O-Mode” Antenna Measures EBW Emission to Evaluate EBW Coupling

- Two 8-18 GHz radiometers simultaneously measure orthogonal polarizations with quad-ridged antenna
- Optimized for 16-18 GHz EBW emission
- Views along 35 degree B field pitch, suitable for NSTX plasmas with  $I_p \sim 1$  MA at  $B_t(0) \sim 4.0$  kG



# Ray Tracing Shows 16.5 GHz EBW Emitted Locally from $R \sim 0.9$ m

EBW Emission Frequency = 16.5 GHz



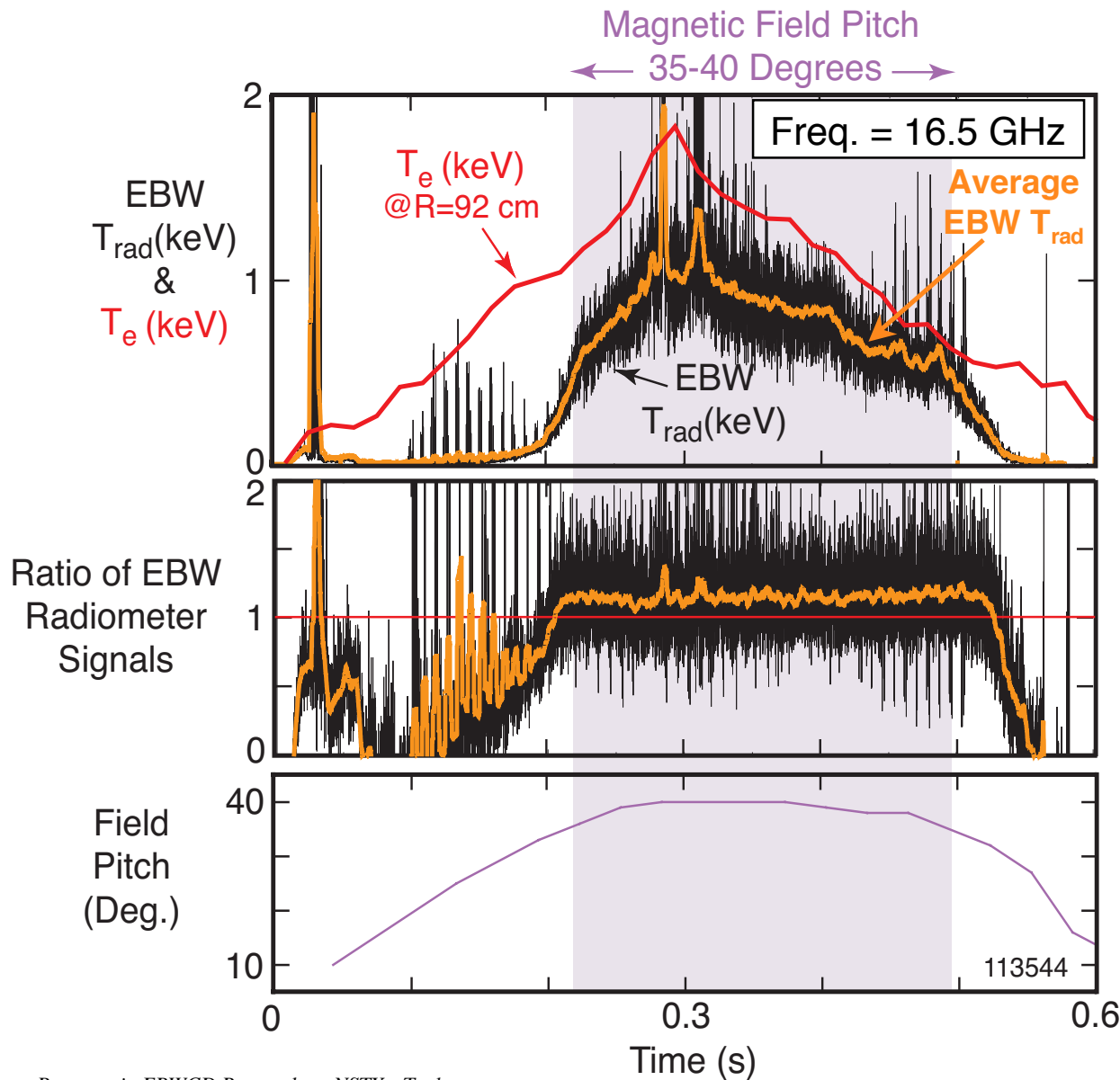
- Antenna view larger than 90% EBW conversion region

[J. Preinhaelter - EBW ray tracing, see Poster PP1.013 Thursday afternoon]

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# Measured ~70% EBW Conversion with Signal Ratios Consistent with Approximately Circular Polarization



- Emission fluctuations due to fluctuation in  $L_n$  at EBW conversion layer
- Radiometer signal ratio  $\sim 1.2$ , consistent with expected near-circular polarization :  
 → *need additional measurements to confirm circular polarization*

# Summary

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- Off-axis CD critical to sustained high  $\beta$  ST operation
- EBWCD modeling predicts efficient off-axis Ohkawa CD resulting from strong diffusion near trapped-passing boundary
- Calculations predict  $\sim 3$  MW of 28 GHz EBW power is sufficient to drive  $\sim 100$  kA at  $0.4 < r/a < 0.8$ , needed to sustain  $\beta \sim 40\%$ .
- Obliquely viewing, quad-ridged, EBW emission antenna demonstrated  $\sim 70\%$  EBW coupling
- EBW radiometer signals consistent with expected near-circularly polarized emission





## Future Work

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- Two 20-40 GHz EBW radiometers & quad-ridged antenna will study “O-mode” EBW emission and 28 GHz coupling
- Include relativistic EBW ray tracing in GENRAY and integrate GENRAY/CQL3D in TRANSP; evaluate effect of transport on CD  
*[A.K. Ram, et al., Poster JP1.016, Wed. PM]*
- Model EBW conversion & coupling with realistic antenna geometry  
*[M.D. Carter, et al., Poster JP1.017, Wed. PM]*
- Benchmark GENRAY/CQL3D against BANDIT (Culham, UK) & DKE/R2D2 (MIT) *[J. Decker, et al., Poster PP1.084, Thurs. PM]*
- 3 MW EBW (4 MW RF source power) system planned to provide > 100kA off-axis EBW CD at  $\beta \sim 40\%$  on NSTX  
*[M.A. Shapiro, et al., Poster JP1.018, Wed. PM]*

