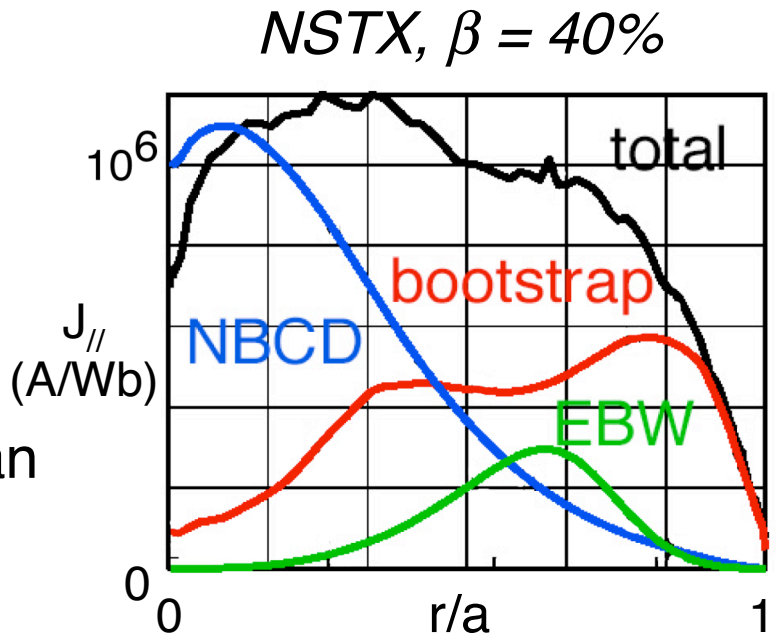
Electron Bernstein Wave Research and Plans

Gary Taylor

Presentation to the 16th NSTX Program Advisory Committee
September 9, 2004

EBWs Can Generate Critical Off-Axis Current Drive in NSTX at High β

- ~ 100 kA of off-axis CD needed to sustain β ~ 40% in NSTX
- Cannot use ECCD in NSTX since ω_{pe}/ω_{ce} ~ 3-10
- Modeling indicates that EBWCD can provide needed current
- EBWCD may also assist startup and stabilize NTM's



Charles Kessel (*PPPL*)
Tokamak Simulation Code

- 4 MW, 28 GHz EBWCD system is being planned for NSTX

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EBW Launcher Design Guided by Modeling EBW Coupling, Ray Tracing and Emission Measurements

- EBW coupling at 14 GHz has been modeled with OPTIPOL/GLOSI
  [Mark Carter, ORNL]

- Coupling at 28 GHz being modeled with OPTIPOL/AORSA1D
  [Mark Carter & Fred Jaeger, ORNL]

- EBW emission measurements on NSTX and other machines can test EBW coupling predictions:
  - *EBW emission also studied as a possible $T_e(R,t)$ diagnostic*

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Modeling Predicts Efficient EBW Coupling with Oblique, Circularly Polarized, "O-Mode" Launch

- "X-mode" EBW coupling requires steep density gradient at EBW conversion layer:
  - *need L_n ~ 2-3 mm for ~100% EBW conversion on NSTX*
  - *need limiter to maintain steep L_n*
  - *very sensitive to L_n fluctuations*
- Oblique "O-mode" EBW conversion efficiency less sensitive to fluctuations in L_n at EBW mode conversion layer
- Theory predicts launch with near-circular polarization provides ~100% EBW conversion efficiency

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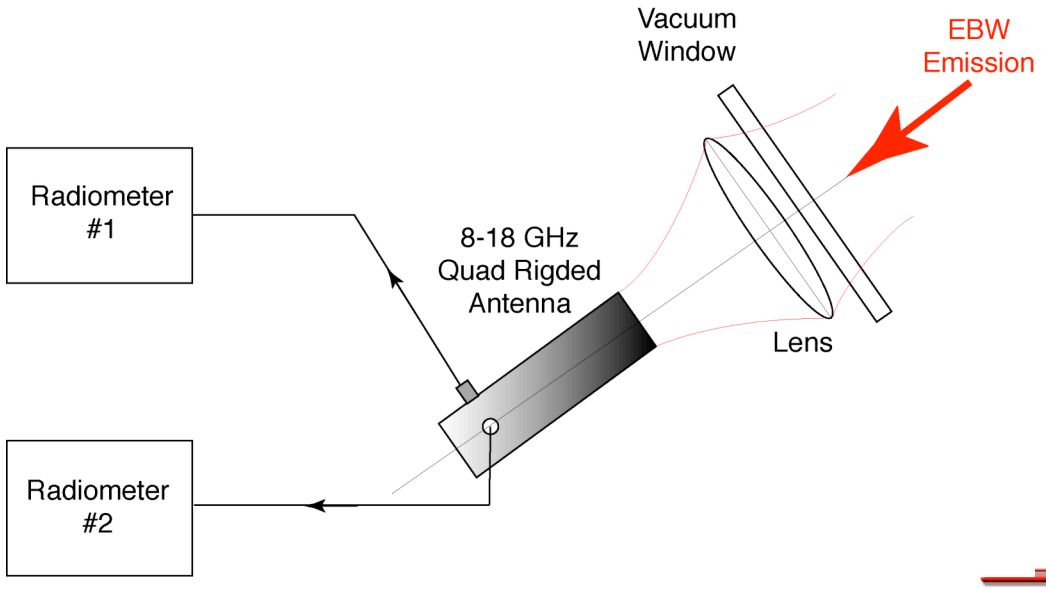
New Obliquely Viewing Antenna Installed on NSTX Measures "O-Mode" EBW Emission

- Two 8-18 GHz radiometers simultaneously measure orthogonal polarizations with quad-ridged antenna:
  - *compare emission results to OPTIPOL/GLOSI coupling predictions*
- Focusing lens optimized for 16-18 GHz EBW emission
- Antenna 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



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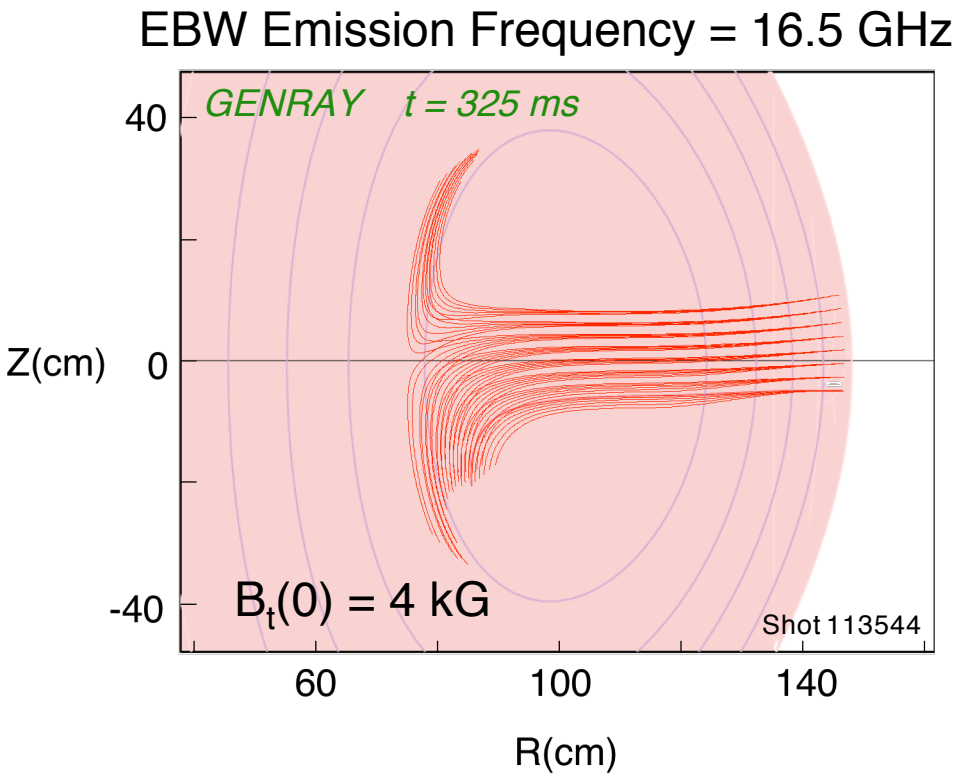
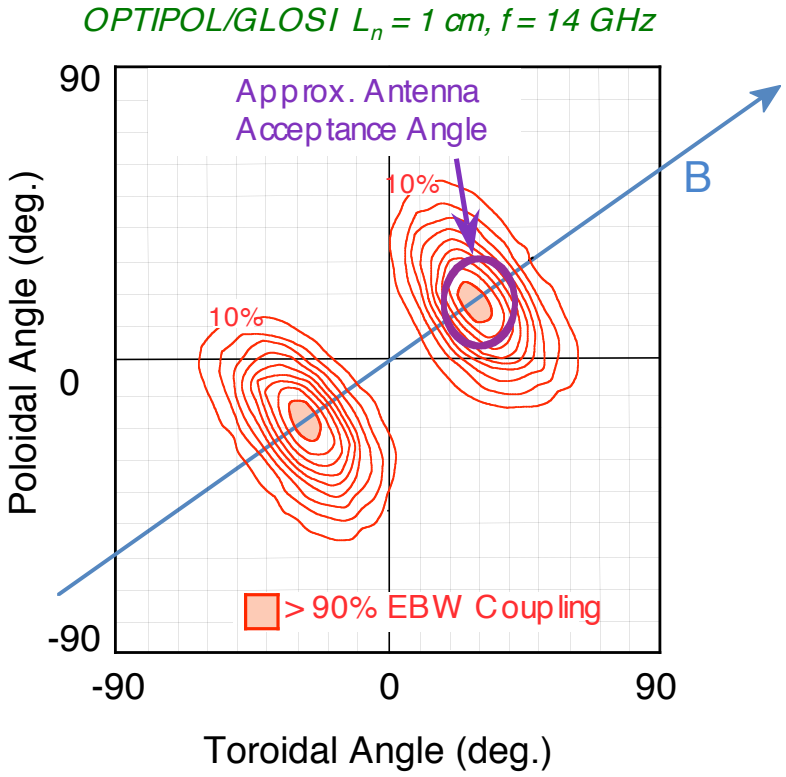
Ray Tracing Calculations Show 16.5 GHz EBW Emission is Generated Locally at r/a = 0.4





- GENRAY ray tracing uses EFIT equilibrium and $T_e(R)$ & $n_e(R)$ from Thomson scattering
- Antenna acceptance angle much larger than predicted 90% EBW conversion region

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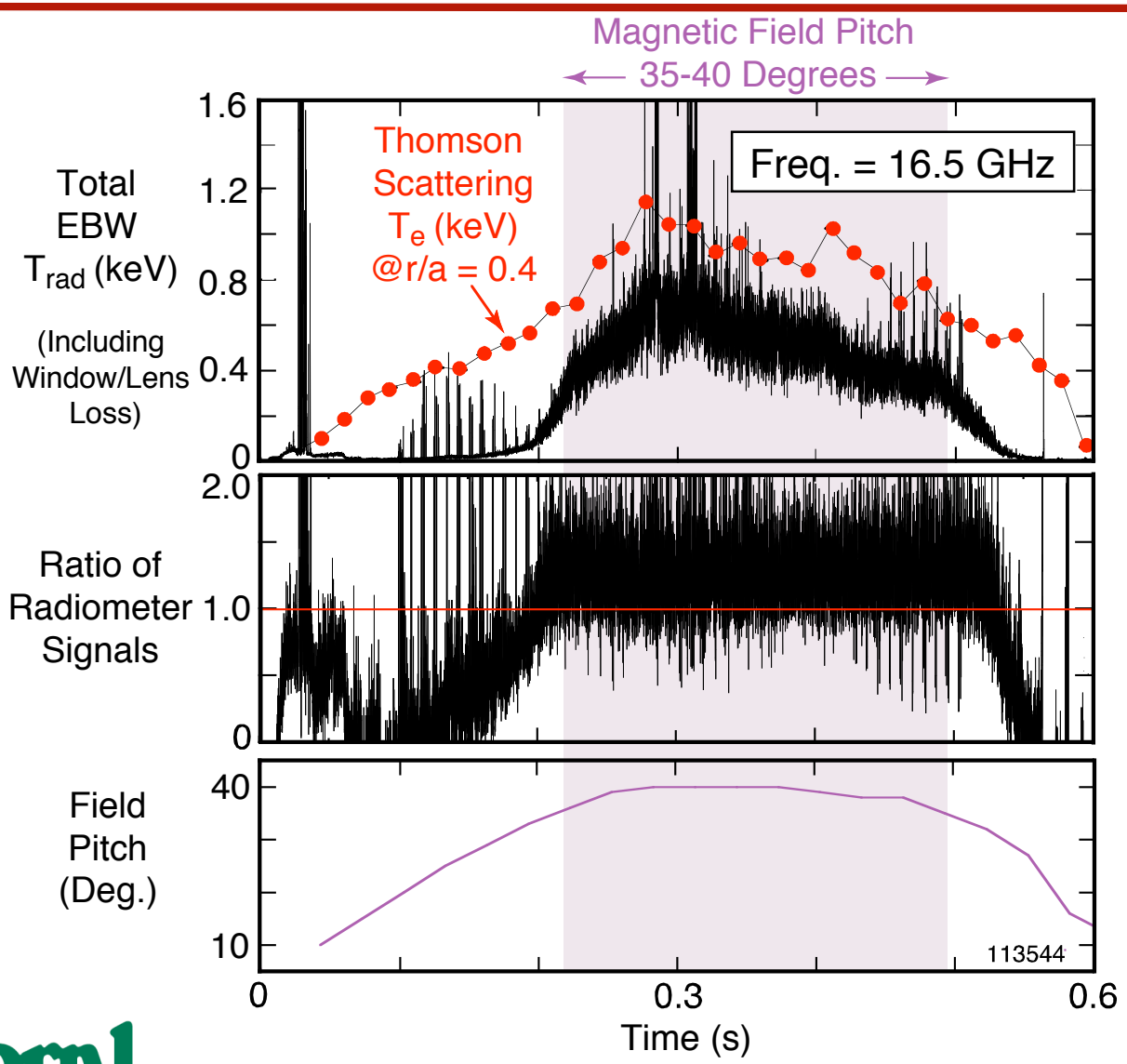
EBW Emission Analysis Indicates Near-Circular Polarization & EBW T_{rad}/T_e ~ 70%; Consistent with Theory



- Emission fluctuations due to fluctuation in L_n at EBW conversion layer
- Fluctuations should be smaller at 28 GHz:
  - *smaller antenna acceptance angle*
  - *smaller L_n fluctuation*

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Obliquely Viewing 20-40 GHz EBW Radiometer to Measure 28 GHz EBW Mode Conversion on NSTX Next Year

- Larger vacuum window & higher frequency should allow much better collimation:
  - *current 16-18 GHz antenna has ± 12 degree acceptance angle, 20-40 GHz antenna should achieve less than ± 5 degrees*
- Detailed 28 GHz coupling study using OPTIPOL/AORSA1D and realistic EBW launcher model planned for FY05:
  - *compare to 28 GHz emission measurements*
- ~ 1 MW, 60 GHz and ~ 100 kW, 28 GHz EBW experiments on MAST will also test oblique "O-mode" conversion theory

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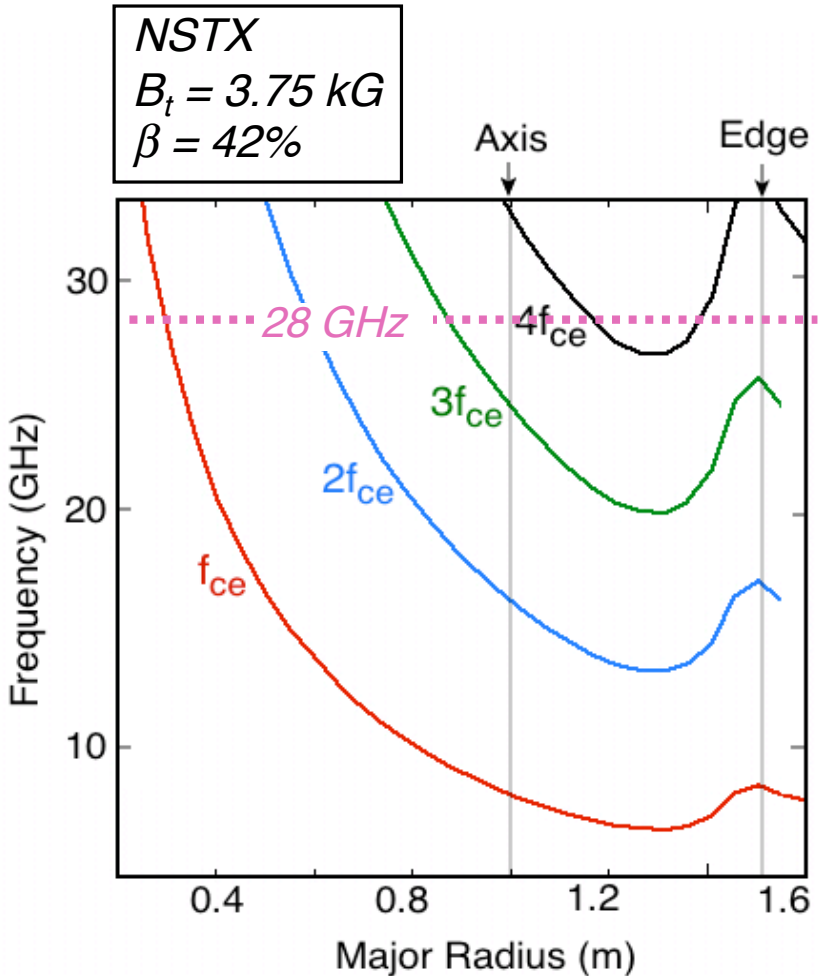
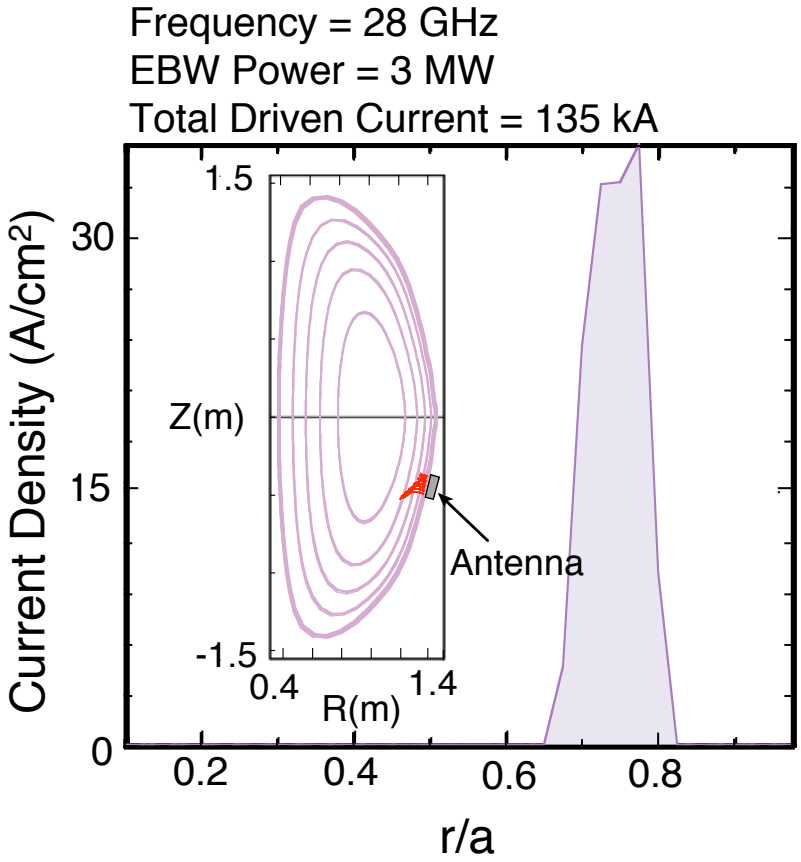
Modeling Predicts 28 GHz EBW Drives Efficient Off-Axis Current at β ~ 40% via Ohkawa CD Mechanism





GENRAY/CQL3D [Bob Harvey, CompX]

G. Taylor et al, Physics of Plasmas (October 2004)

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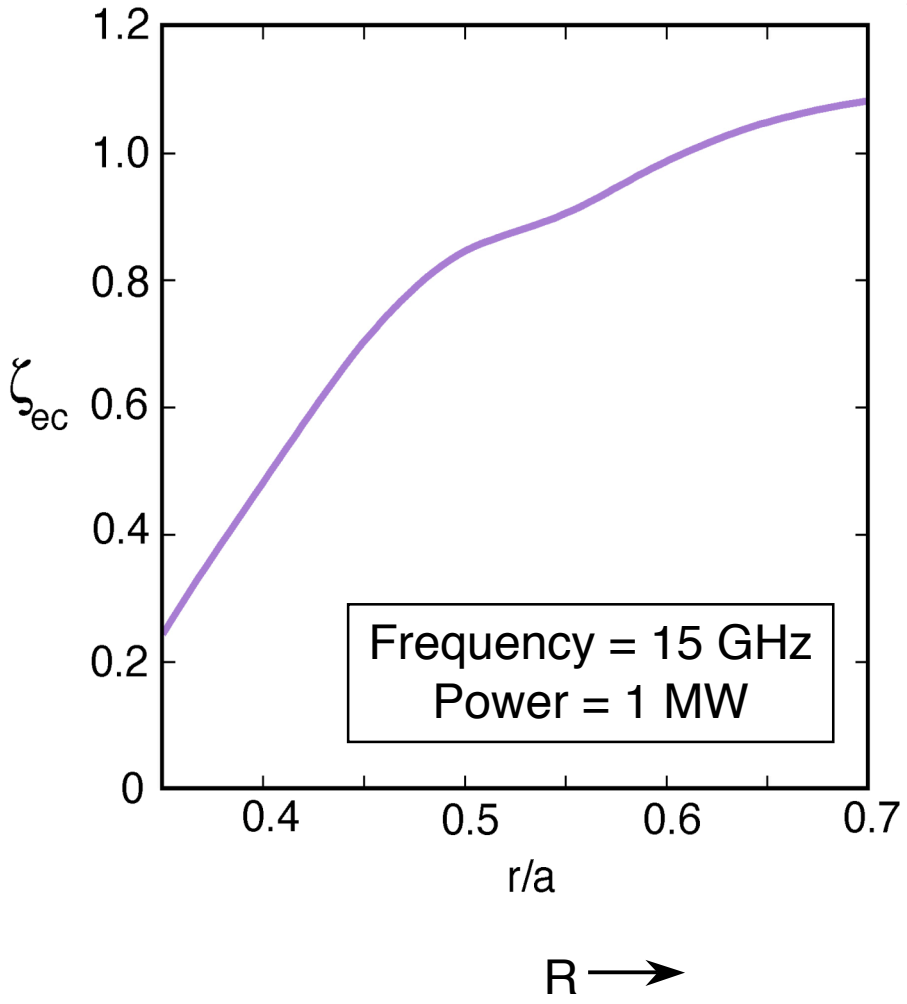
Normalized Ohkawa EBWCD Efficiency (ζ_{ec}) Increases with r/a on Low Field Side of Axis

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

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



- Initial estimates suggest interaction with bootstrap current may modify EBWCD efficiency by ~10%
- Will extend EBWCD modeling to include bootstrap current, trapped particle pinch and electron transport

CompX *GENRAY/CQL3D*

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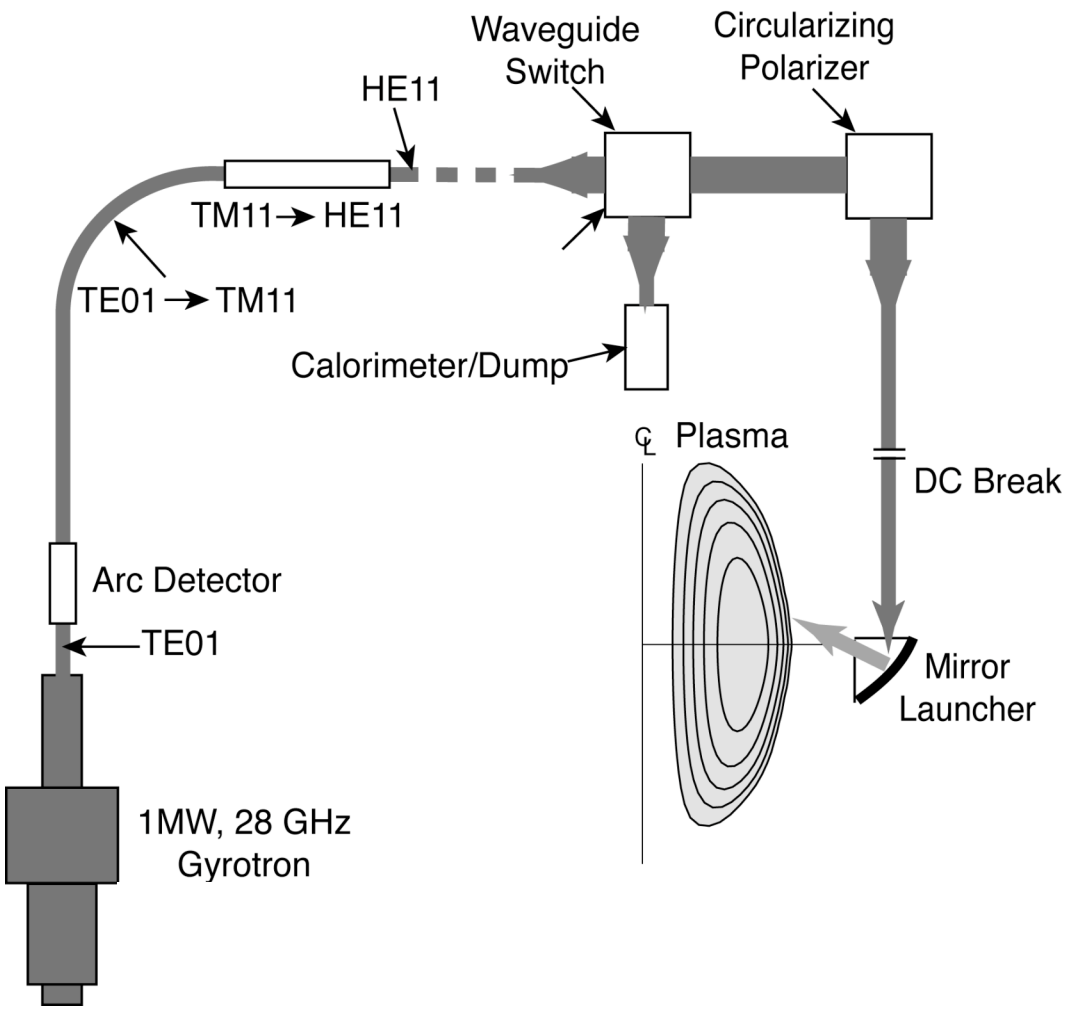
1 MW "Proof-of-Principle" EBW System Tests Viability of Heating & Current Drive in NSTX



- ~ 750 kW EBW power delivered to plasma:
  - *allowing for transmission loss and EBW conversion*
  - *drive 30-40 kA*
- Final 4 MW system will add three more gyrotrons, transmission lines & launchers
  - *provides 3 MW of EBW power in the plasma & generates > 100 kA*

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Summary

- We are looking at 28 GHz EBWCD for NSTX
- Initial emission results at 16-18 GHz via EBW conversion to "O-mode" look promising & consistent with theory
- We will measure 28 GHz EBW emission via "O-mode" conversion next year
- Modeling EBW coupling is now being extended to 28 GHz
- EBWCD modeling results show efficient Ohkawa off-axis CD & predict ~ 3 MW of EBW power will drive > 100 kA

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