The 28GHz ECH System on HSX and Initial O2 Startup Tests

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Realta ECH Workshop
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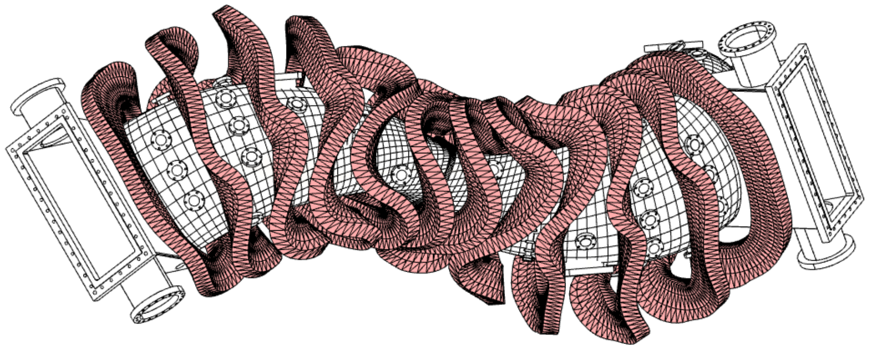

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Outline

- 28GHz Gyrotron and Support Systems
- 28GHz Hybrid Transmission Line
- X2 Absorption at 0.5T
- O1 Absorption at 1.0T
- O2 Launching at 0.5T
- EBW Heating Calculations

28GHz Gyrotron and Support Systems

Gyrotron – CPI/Varian VGA-8050M

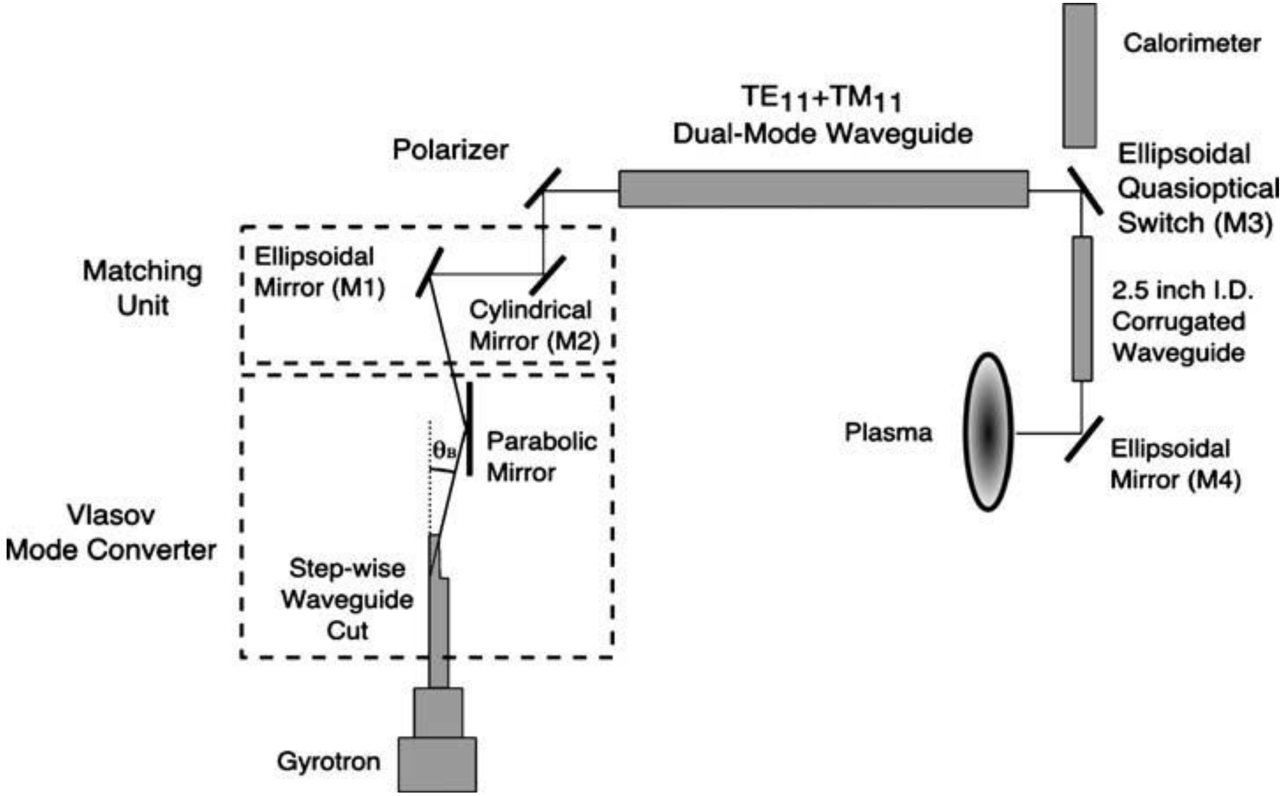
- 0-250kW output power, 0.75 max pulse length
- 60-80kV cathode voltage
- Anode controlled (triode type tube)
- Copper coils (big power supplies
- Used on TMX at LLNL in ‘80s, acquired in ‘90s
- In service almost continuously since ~’97

Support Systems

- Beam power supplied by oil filled capacitors with vacuum tetrode output, from late ‘70s
- Five generations of homemade control systems
- Works great

28GHz Hybrid Transmission Line

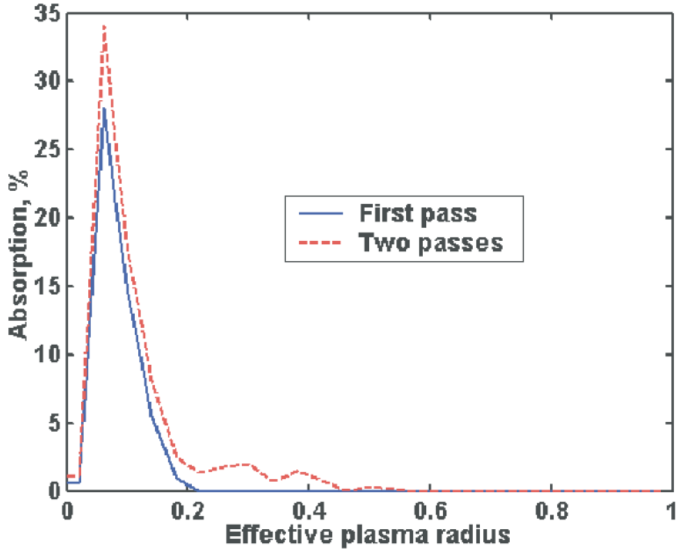
- TE02 to TEM “Vlasov Converter”
- “Dual Mode” smooth, cylindrical waveguide (three beats long)
- Phase-corrected quasioptical / HE_{11} transmission to dummy load or plasma
- Dry nitrogen purge



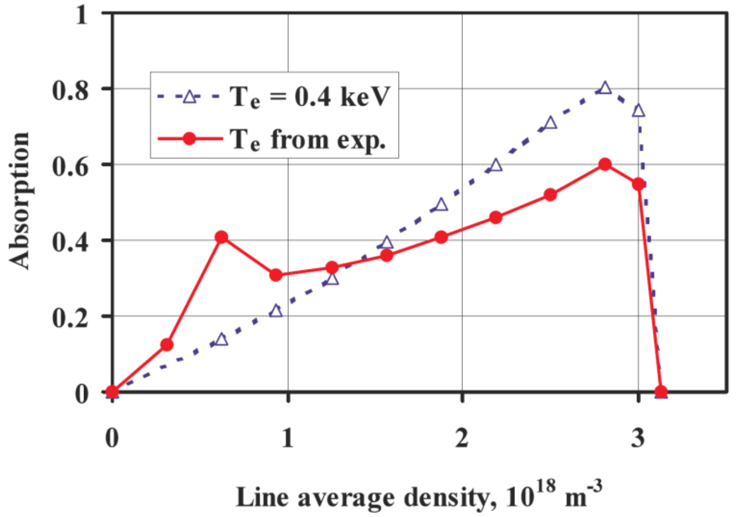
J.W. Radder, Hybrid Transmission Line for ECRH in HSX, Int J Infrared Milli Waves (2008) 29:360-372

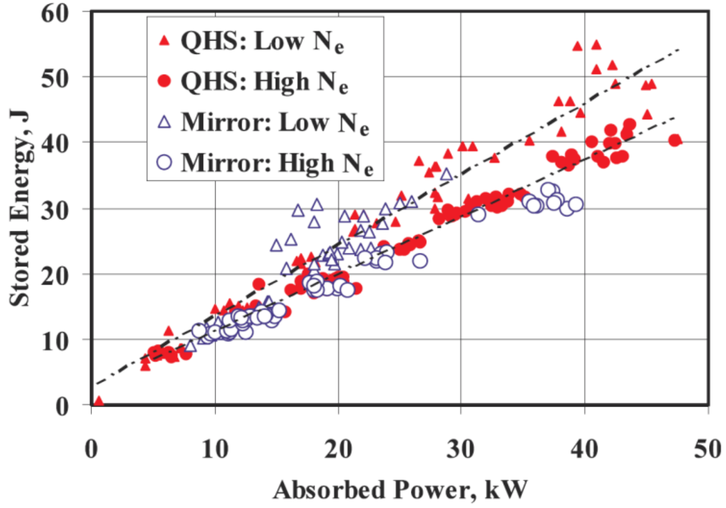
X2 Absorption at 0.5 Tesla

- X2 absorption is highly local
- Limited by low temperatures and densities at 0.5T operation
- Stored energy scales nicely with power
- Suprathermals consume a portion of launched power at low density



X2 absorption calculated with
B_0=0.5T, n_{eo}=2.0 x$10^{18}m^{-3}$, T_{eo}=0.4keV

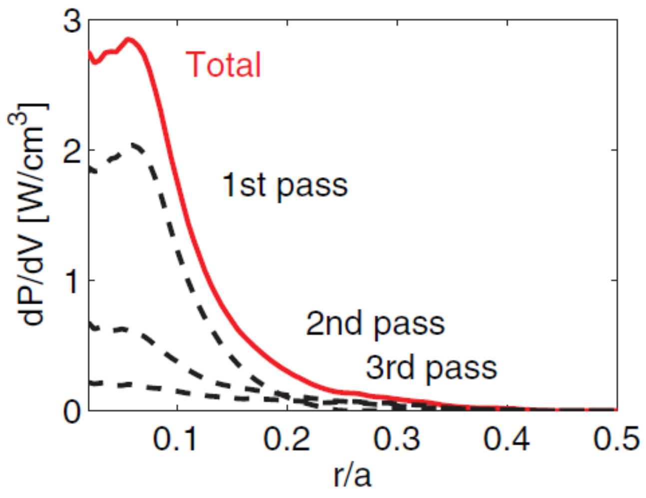


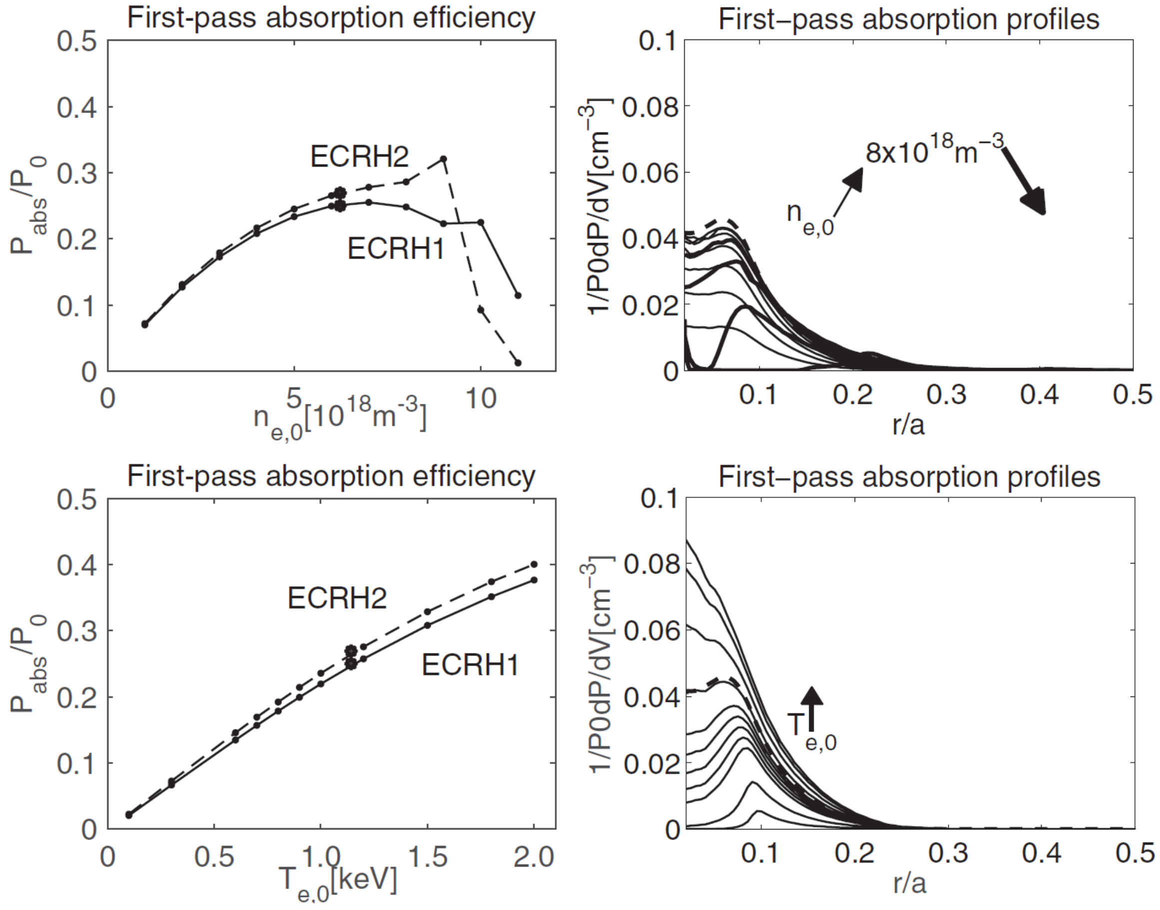


K.M. Likin, Comparison of electron cyclotron heating results…, Plasma Phys. Control. Fusion 45 (2003) A133-A142

O1 Absorption at 1.0 Tesla

- O1 absorption is less local than X2
- Limited primarily by T_e
- Multi-pass absorption is found to raise absorption efficiency to ~50%

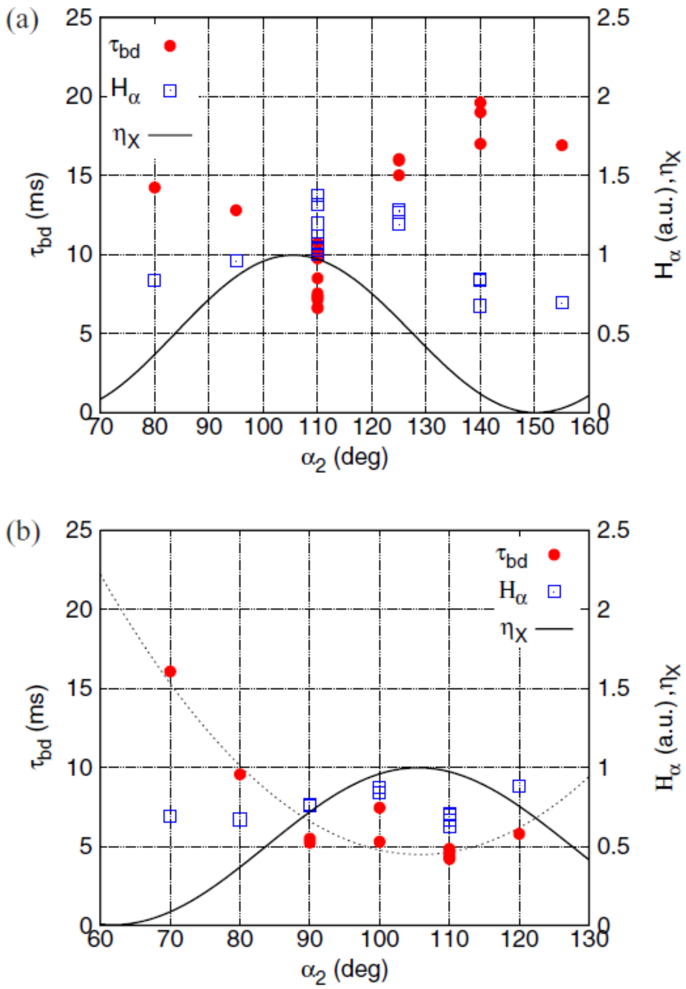




G.M. Weir, Ray tracing and ECRH absorption modeling in the HSX Stellarator, Nuclear Fusion 55 (2015) 113011

O2 Launching at 0.5 Tesla, TJ-II Results

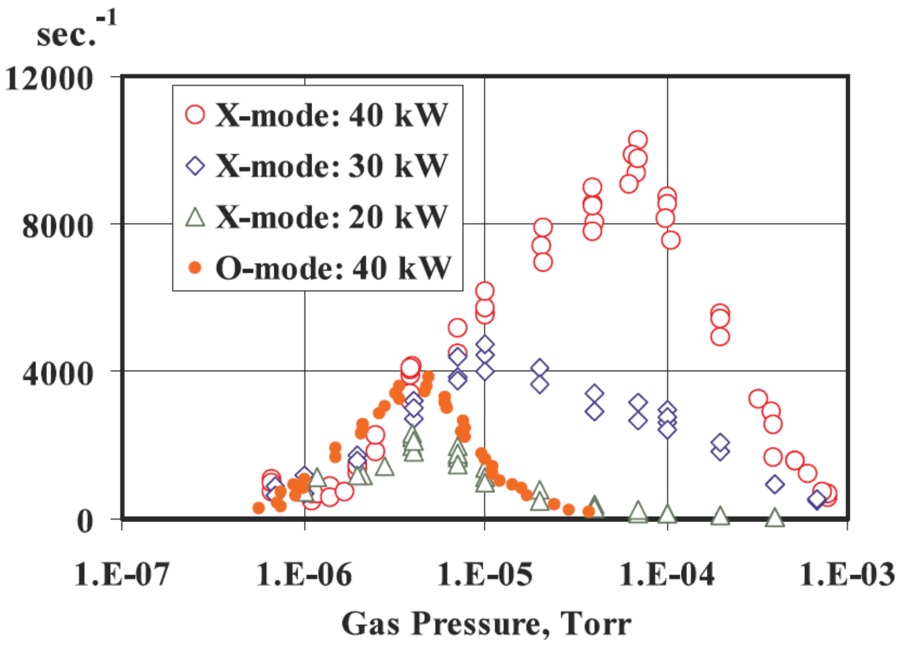
- TJ-II was able to achieve plasma breakdown and heating with O2 launching
- **No increase in accessible plasma density was reported with O2 launching**
- Absorption was found to be poor, demonstrated by longer time to breakdown proportional to O2 polarization fraction
- O2 breakdown is assumed to be due to scattering of shine-through off vessel wall and de-polarization, resulting in sufficient X2 fraction to cause breakdown



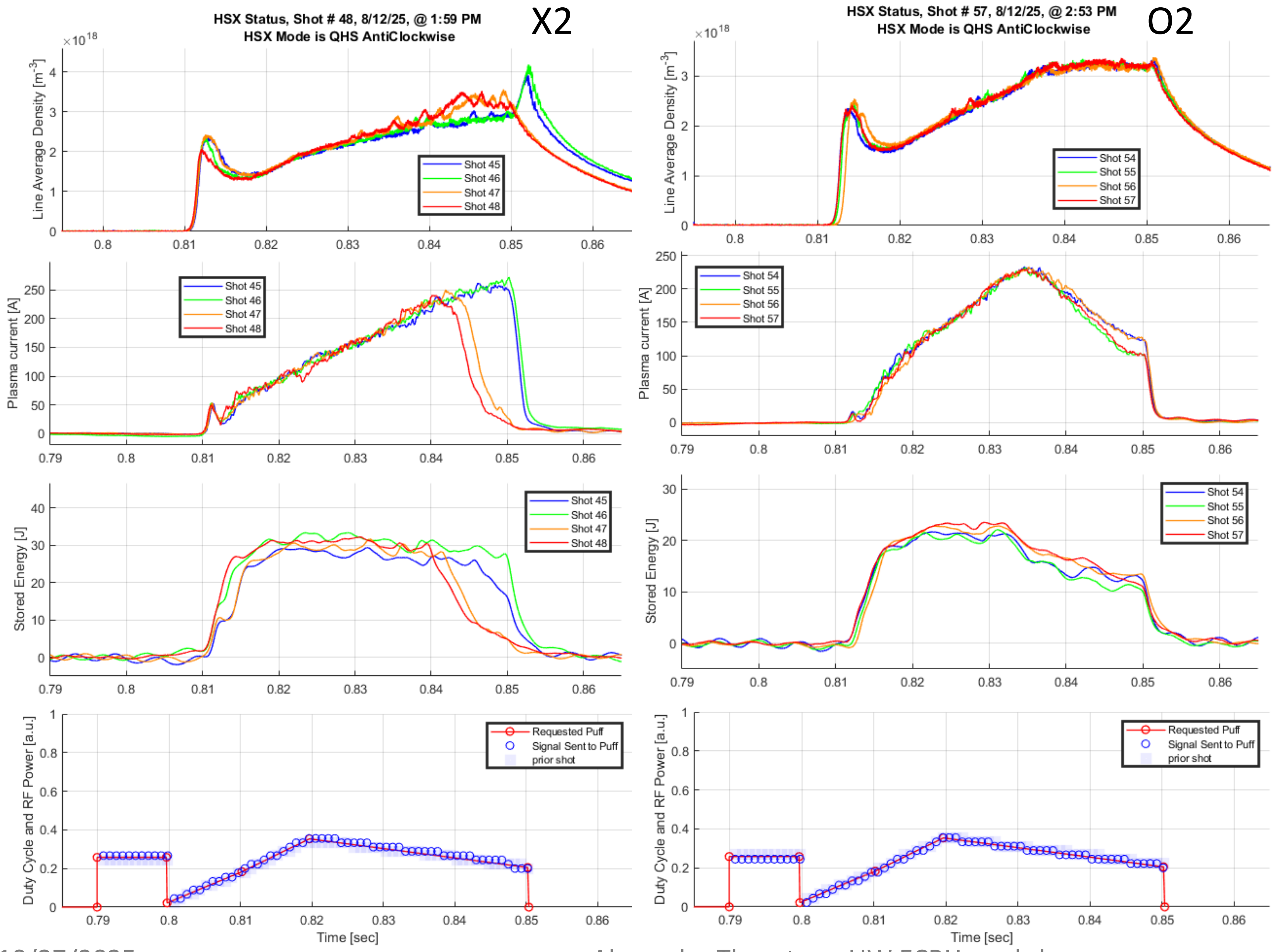
A. Cappa, Second harmonic ECRH breakdown experiments in the TJ-II stellarator, Nucl. Fusion 55 (2015) 043018

O2 Launching at 0.5 Tesla, Old HSX Results

- Density scans were done on HSX using X2 and O2 launching c. 2002
- **No increase in accessible plasma density was found with O2 launching**
- O2 launched density ramp-up time was consistent with X2 at low density but fell off at medium density
- Densities near X2 cutoff could not be ionized in O2
- Gas fueling was done by filling the vessel before a shot, no high-speed "puffing" was available



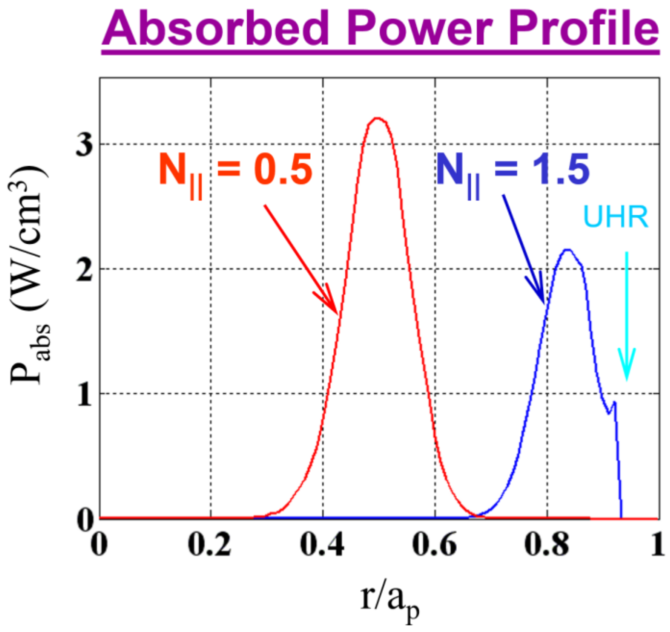
O2 Launching at 0.5 Tesla, Recent HSX Results



- Density scans done in both X2 and O2 this year
- **No increase in accessible plasma density was found with O2 launching**
- Cutoff behavior is less sharp in O2, presumably due to wider beam at absorption layer
- Power scans and resonance location scans were also performed, no interesting results were found

EBW Heating Calculations Done for HSX

- EBW Dispersion relation was incorporated into a ray tracing code (K. Likin)
- O-X-B conversion efficiency in HSX plasma geometry can be >0.8 for a well focused beam
- Absorption is off-axis and strongly depends on $N_{||}$
- On-Axis heating may be possible if the upper hybrid resonance layer can be moved further inboard



EBW absorption calculated with B_0=1T, n_{eo}=1.2 x$10^{19}m^{-3}$, T_{eo}=2keV

K.M. Likin, “EBW Heating In The Helically Symmetric Experiment” (Poster), 50th APS-DPP, 2008

Summary

- 28GHz ECH has been used for >25 years on HSX
- X2 is absorbed at 0.5 Tesla
- O1 is absorbed at 1.0 Tesla
- O2 can be launched, but there is no increase in accessible plasma density
- Overdense EBW heating has been considered