QOS Project Review
Experimental Considerations

Heating and Current Drive Issues

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Introduction

- **ORNL has substantial ECH, ICRF and LH assets**
- **QOS offer new opportunities in ICRF, ECH and LH**
  - **What are the options**
  - **What do we want?**
- **Worldwide ICRF and ECH experience on stellarators can be applied to QOS**
- **QOS has the access and conditions for ECH and ICRF**

ECH and RF Hardware Assets

- **ECH cw power 10.6 - 53.0 GHz**
  - **0.6 MW at 53 GHz.**
  - **0.2 MW at 56 GHz.**
  - **0.2 MW at 35 GHz.**
  - **0.8 MW at 28 GHz.**
  - **0.04 MW at 18 GHz.**
  - **0.045 at 10.6 GHz.**
  - **ECR discharge cleaning source- 6 kW, 2.45 GHz (0.0875T)**

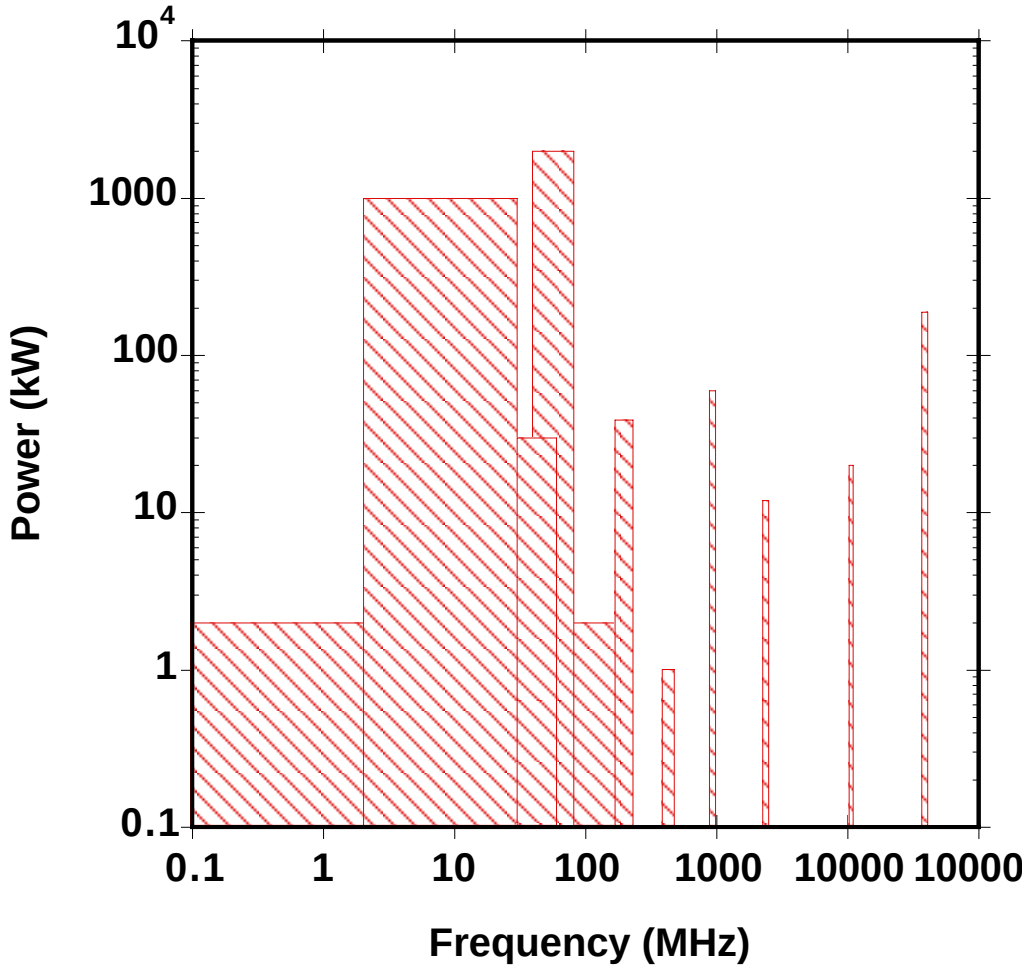
Power supply can handle 2MW

7 - 10 sockets 1.4-2MW

- **Significant ICRF power at 6-20 MHz and 40-80 MHz**
  - **~ 3.5 MW of long pulse RF**
  - **2 - 180 MHz coverage at lower power**
- **Lower hybrid power**
  - **0.5 - 1 MW 2.45 GHz**
  - **~ 120 kW at 915 MHz**
  - **2ea. 250 kW 800 MHz sources at PPPL**

Tim Bigelow

Power and frequency ranges available



ECH and LH Assets

> 2MW ECH supply (pulsed) with 9 sockets/magnets
53 GHz 3ea. 200kW ea.
56 GHz 1ea. 200kW ea.
28 GHz 4ea. 200kW ea. To be loaned to PPPL for NSTX EBW
35 GHz 1ea. 200kW ea.

Possibilities
Russian 53 GHz 1MW ~500K for tube and magnet Socket is extra
Texas 28 GHz ?

Other electron heating options (parallel heating)
Lower Hybrid 2.45 GHz 1MW
HHFW using folded waveguide @ 57 MHz 1.-1.5 MW or
HHFW using strap antenna @ 40-80 MHz 1.5 MW

QOS with ECH Only

ECH power perpendicular electron heating	28 GHz 4 @ 300KW ea. 2^{nd} 28	53 & 56 GHz 4 @ 200KW ea. 2^{nd} 53
Parameter	**low**	**high**
B (T)	0.5	1.0
R (m)	0.83	0.83
a (m)	0.35	0.35
V_p (m^3)	1.78	1.78
P (MW)	1.0	0.5
n (10^{19} m^{-3})	0.45	1.8
$<\beta>$ (%)	1.5	1.02
τ_E (ms)	2.25	12.1
T_{e0} (keV)	3.1	2.1
T_{i0} (keV)	0.30	0.23

ICRF options

- **Minority heating (~ 15 MHz at 1.0 T)**
  - **~ 5 % minority (tail heating)**
  - **~ 30 % minority (bulk ion heating)**
- **Magnetic beach heating (< 15 MHz at 1.0 T)**
  - **bulk ion heating**
- **Direct electron or high harmonic heating (≥20 MHz)**
  - **FW and HHFW bulk electron heating**
- **Mode conversion heating (~ 15 MHz at 1.0 T)**
  - **MC bulk electron heating**
- **LH**
  - **2.45 GHz**
  - **915 MHz**
  - **800 MHz**

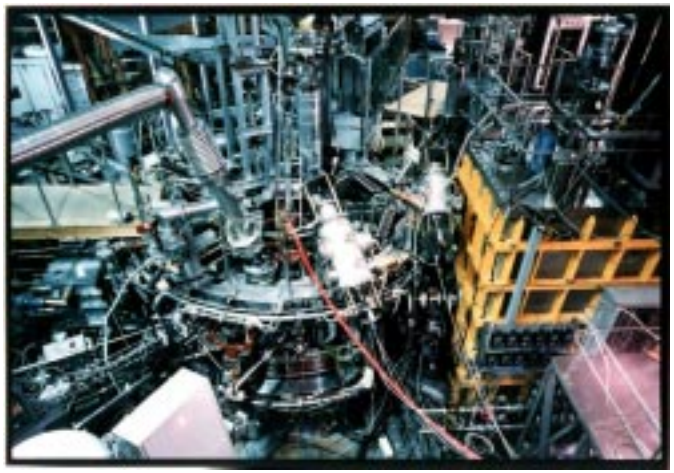
What heating and control do we want?

Open issues for ICRF

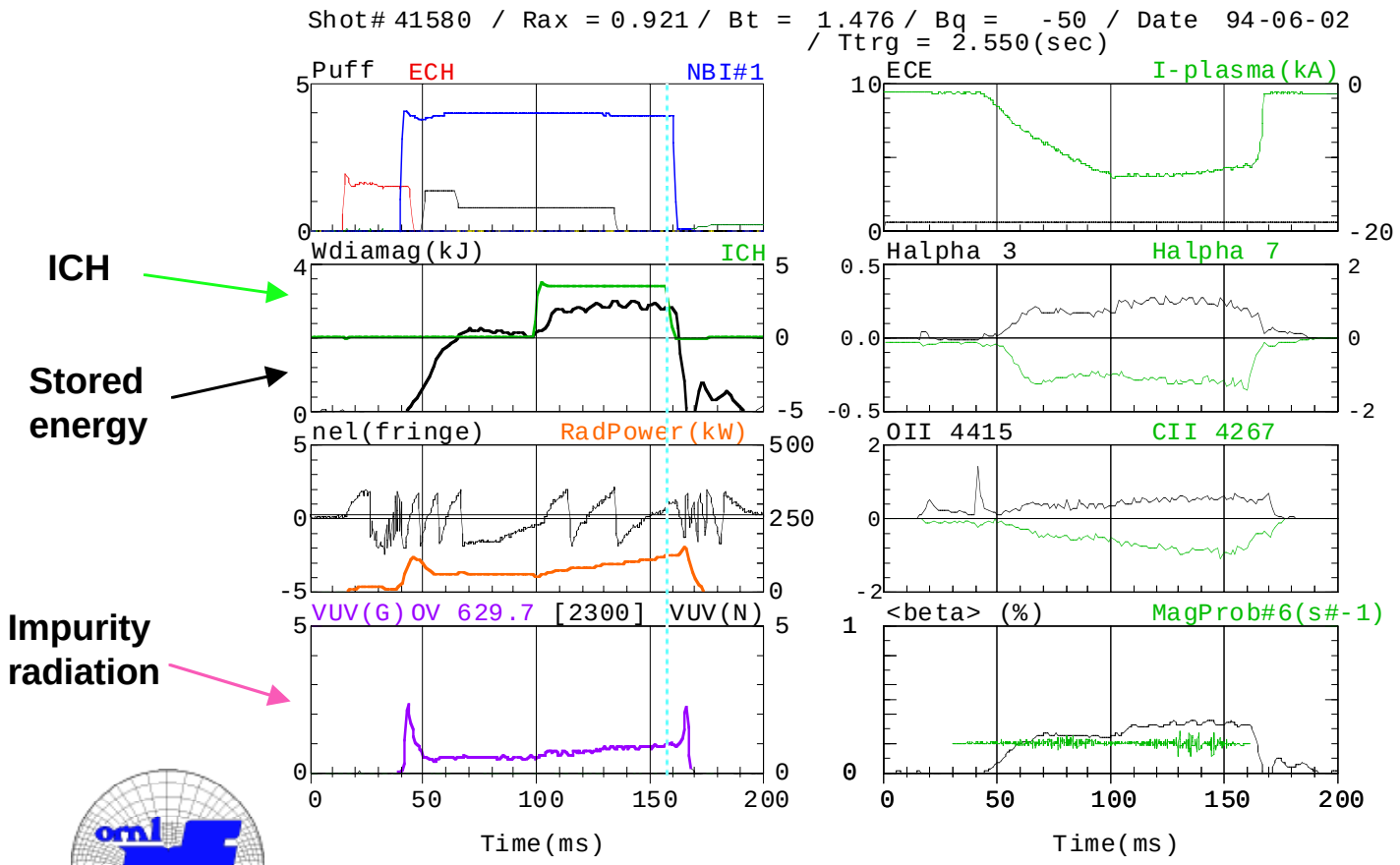
- Electron or ion heating?
- Profile, flow or current control
- Single pass absorption of HHFW or DEH
- Ion confinement (bulk or tail heating)
- ICRF antenna size and directivity (?)
- LH frequency and port size
- Others

CHS Details

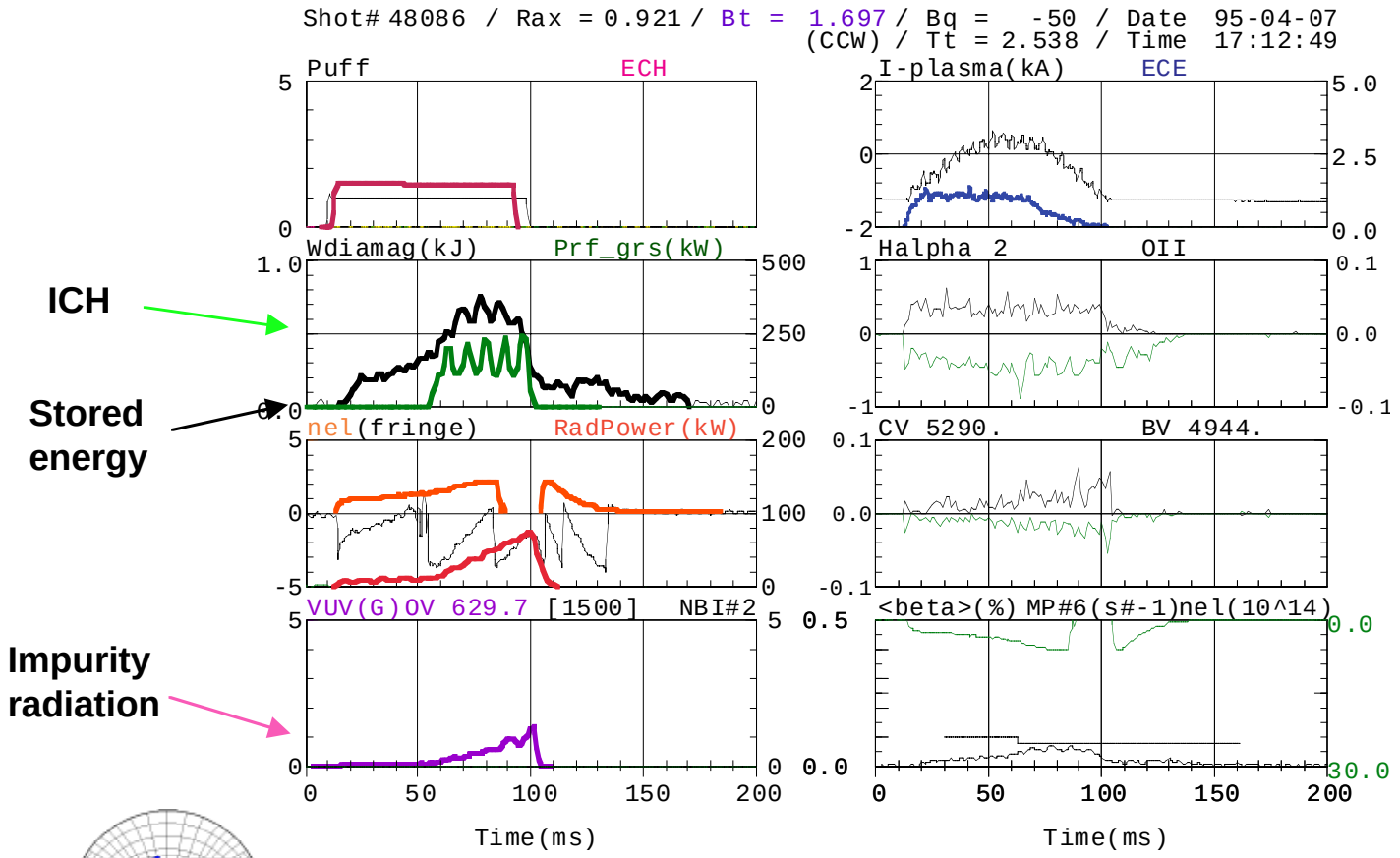
Major radius	1.0 m
Average plasma radius	0.2 m
Plasma aspect ratio	5
Max. Field on Axis B_t	2.0 T
Rotational Transform	
Central	0.33
Edge	0.8 - 1
Heating Power	
ECH	28 GHz 200 kW
	53 Ghz 200 kW
ICRF	7-15 Mhz 800 kW
	9-28 Mhz 500 kW
	20-45 MHz 1.5 MW
NBI	40 kV 1.2 MW



Impurities Remain Low with Combined ICRF and NBI B_T=1.48T



ICRF power modulation effects were observed in the stored energy B_T=1.7T



Magnetic Beach heating on W7-AS

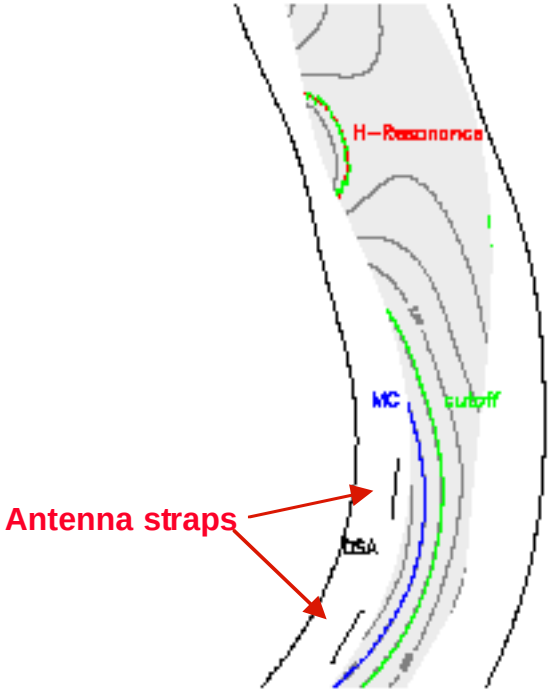


Figure 11: Horizontal cross-section with magnetic field contour lines of a half module in W7-AS for a mirror configuration with two ion hybrid resonance (MC) and associated cutoff. Mirror ratio $M=0.85$.

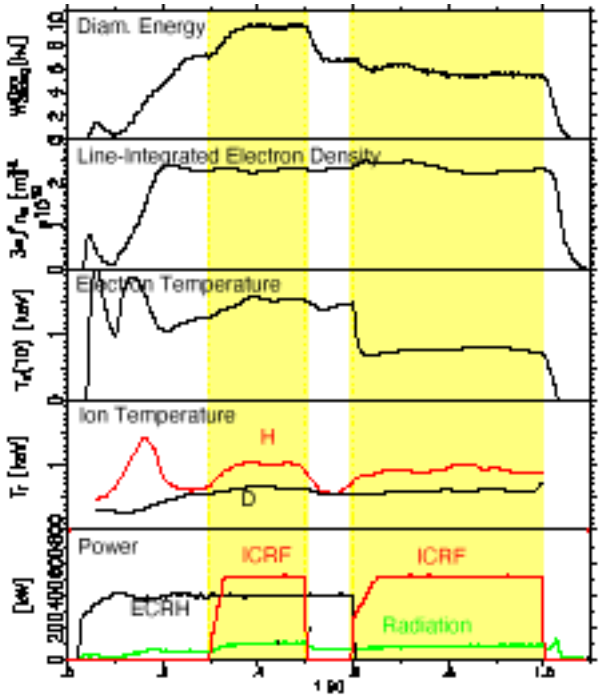


Figure 12: Example shot for magnetic beach heating.

Hartman, et al

Mode conversion heating of electrons and ions on CHS

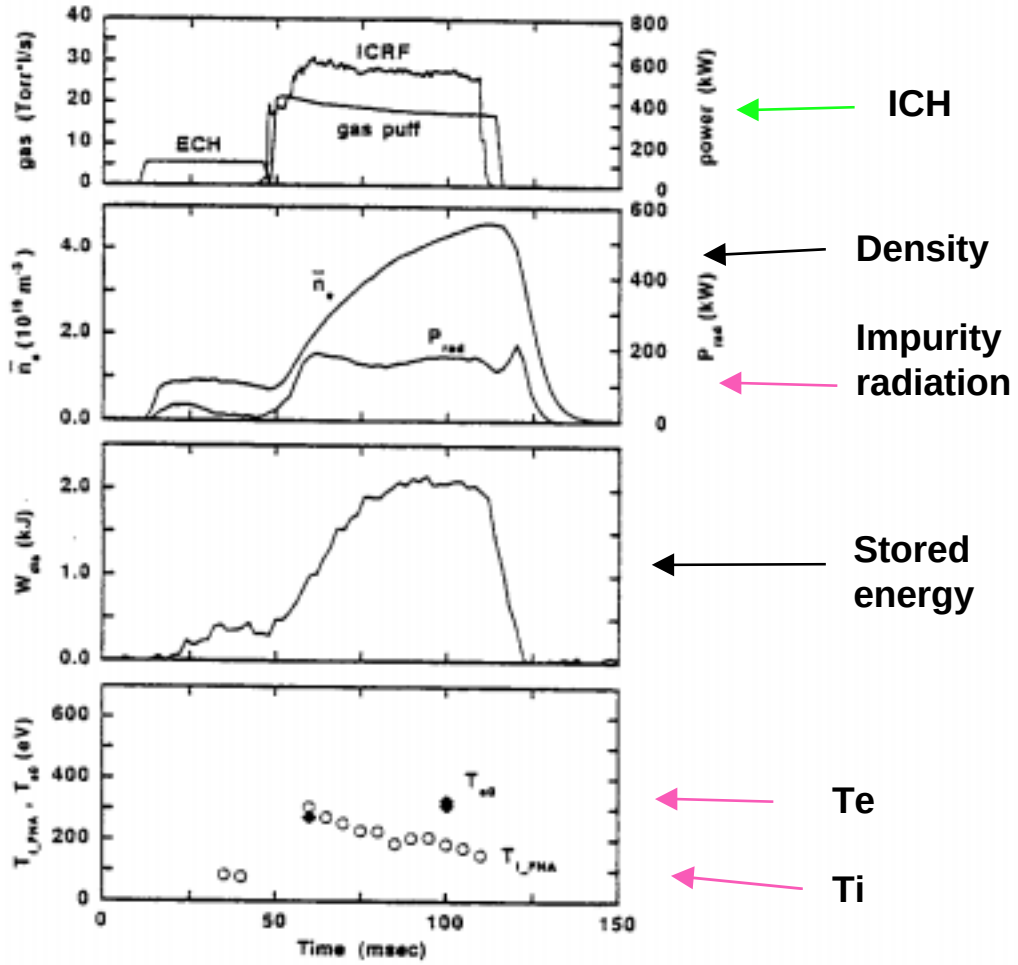
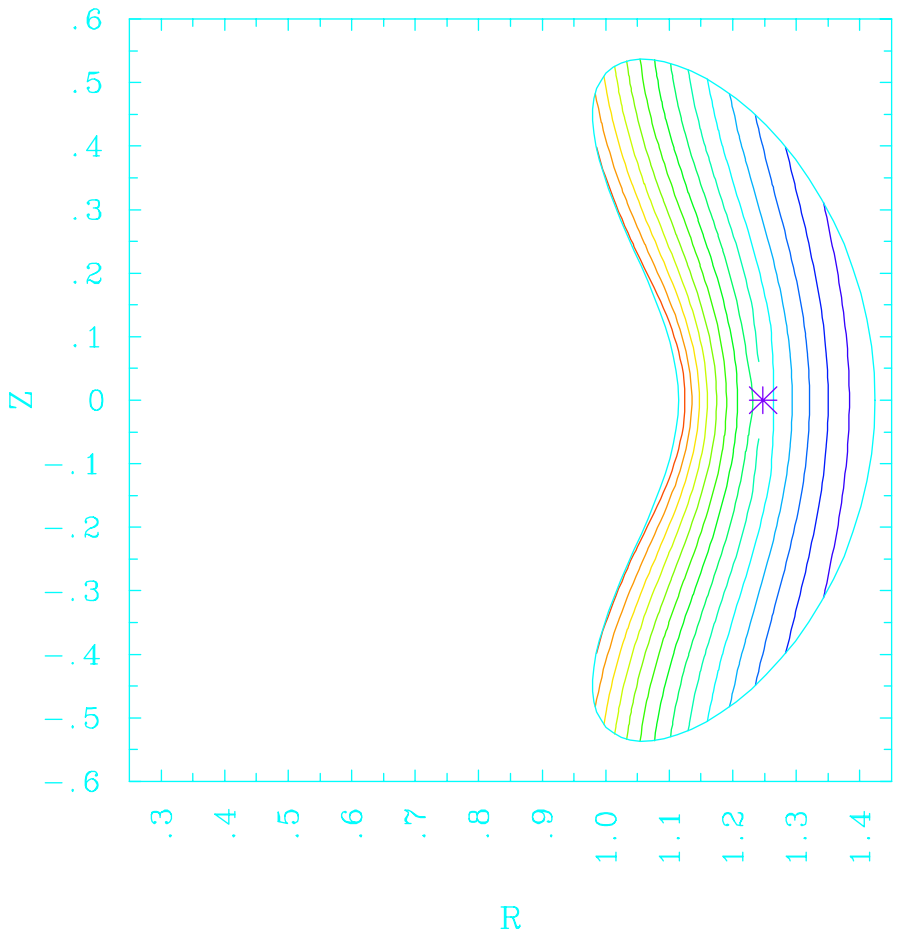


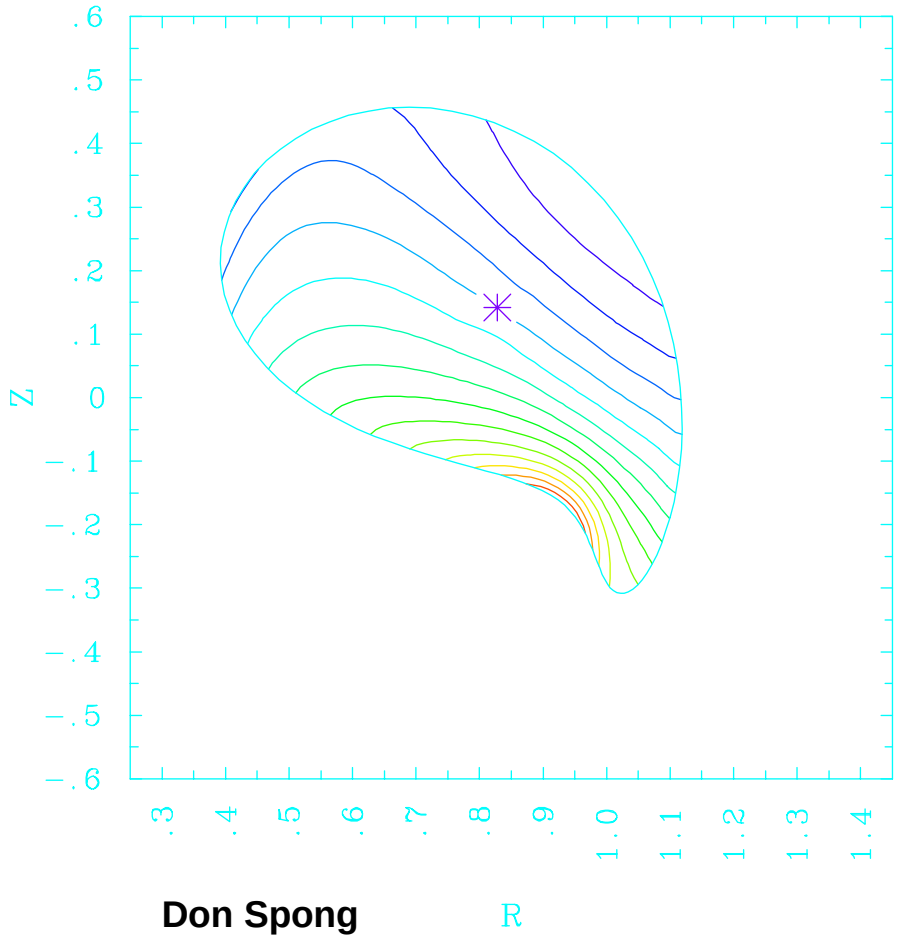
Fig. 3 Temporal evolution of plasma parameters for an ICRF heating experiment (#40991). Top column : gas puffing rate and input power. Second column : line averaged electron density and radiation loss. Third column : stored energy measured by a diamagnetic loop. Bottom column : electron and ion temperature measured by Thomson scattering and NPA, respectively.

Lower hybrid

- **Additional electron heating source**
- **~ 1MW Lower hybrid sources are available**
- **Lower frequency antenna may be too large**
- **2.45 GHz deserves further study**

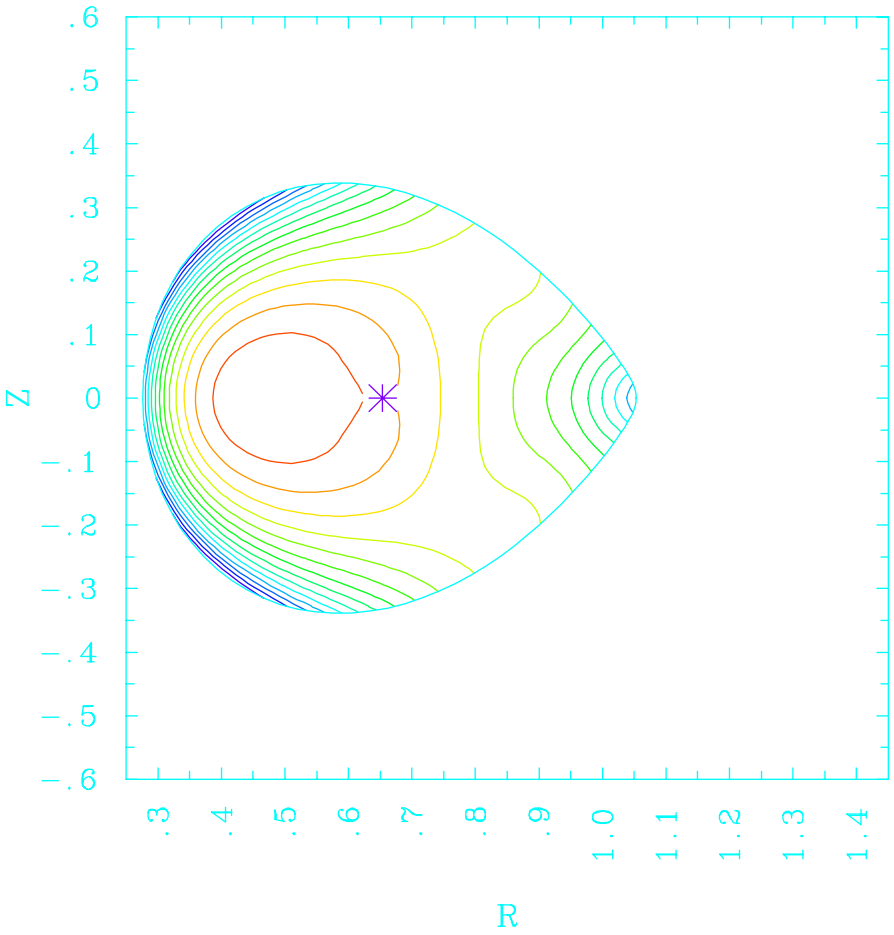
Mod-B Contours

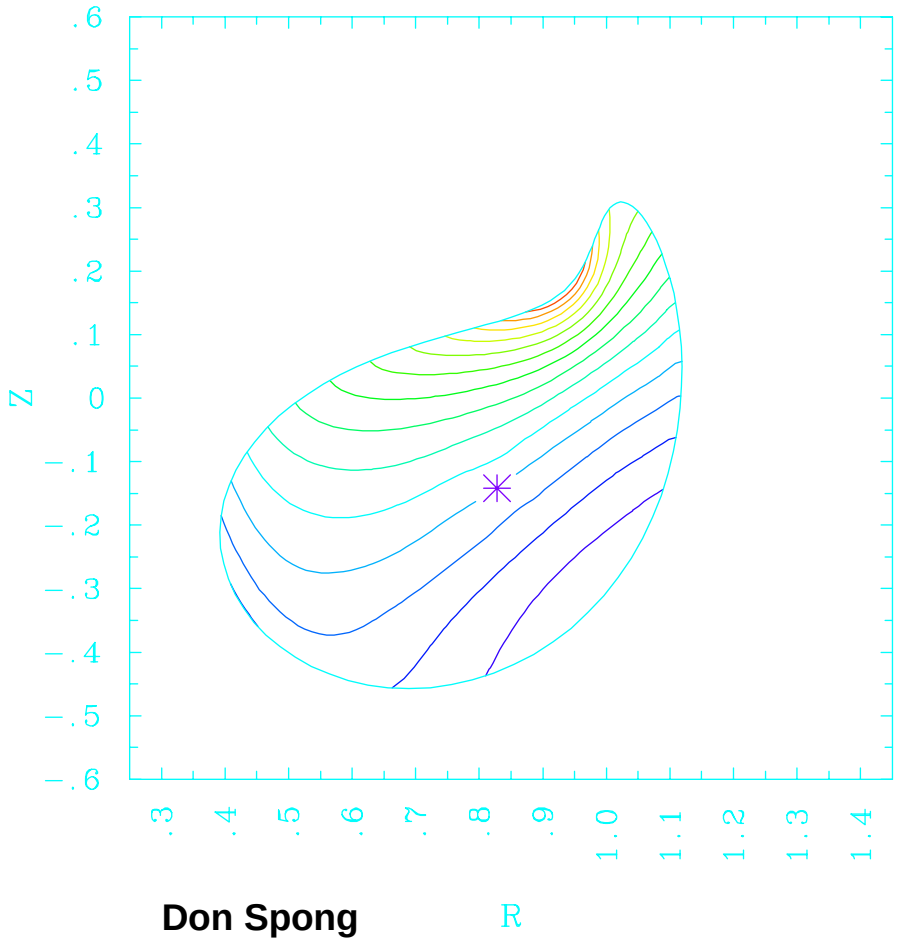




Don Spong

Mod-B Contours





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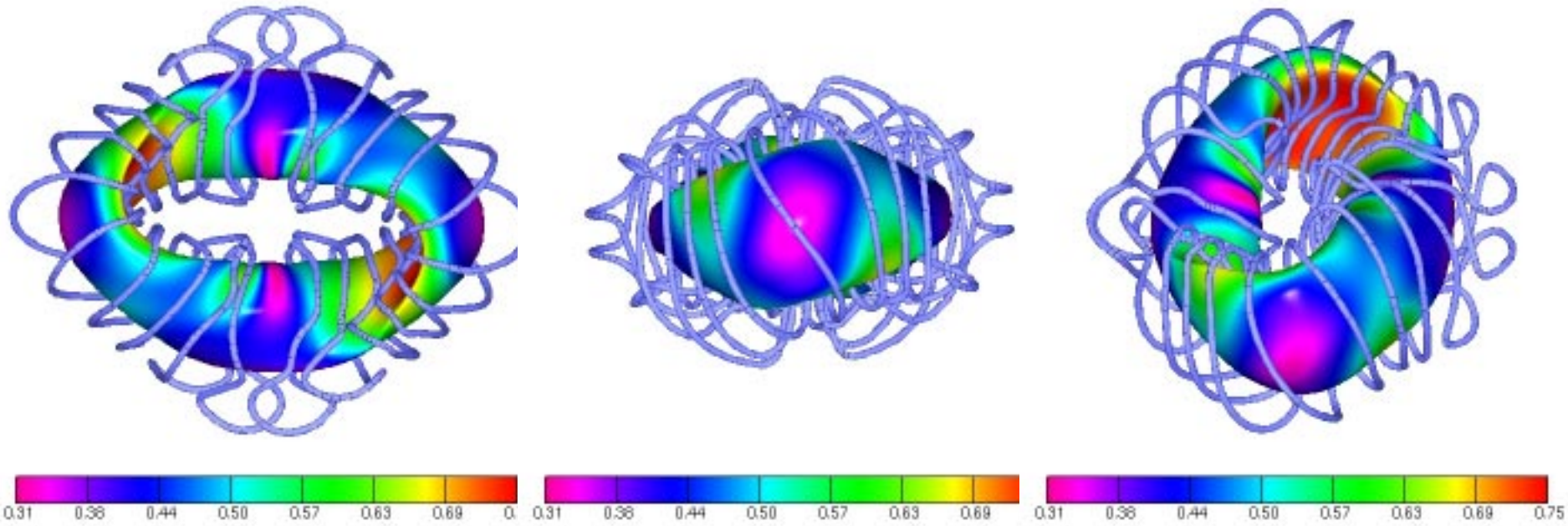
Good access between and under coils



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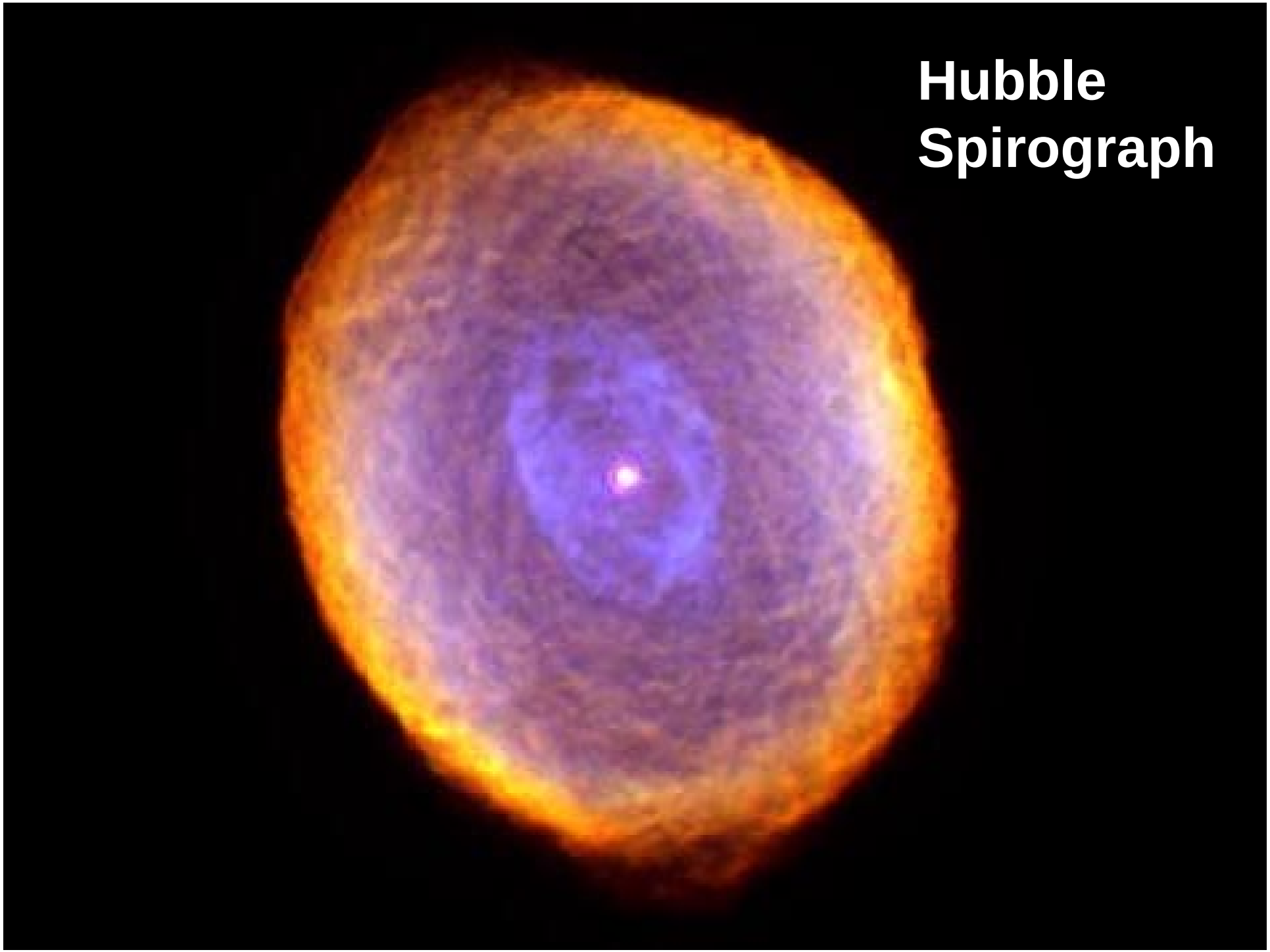
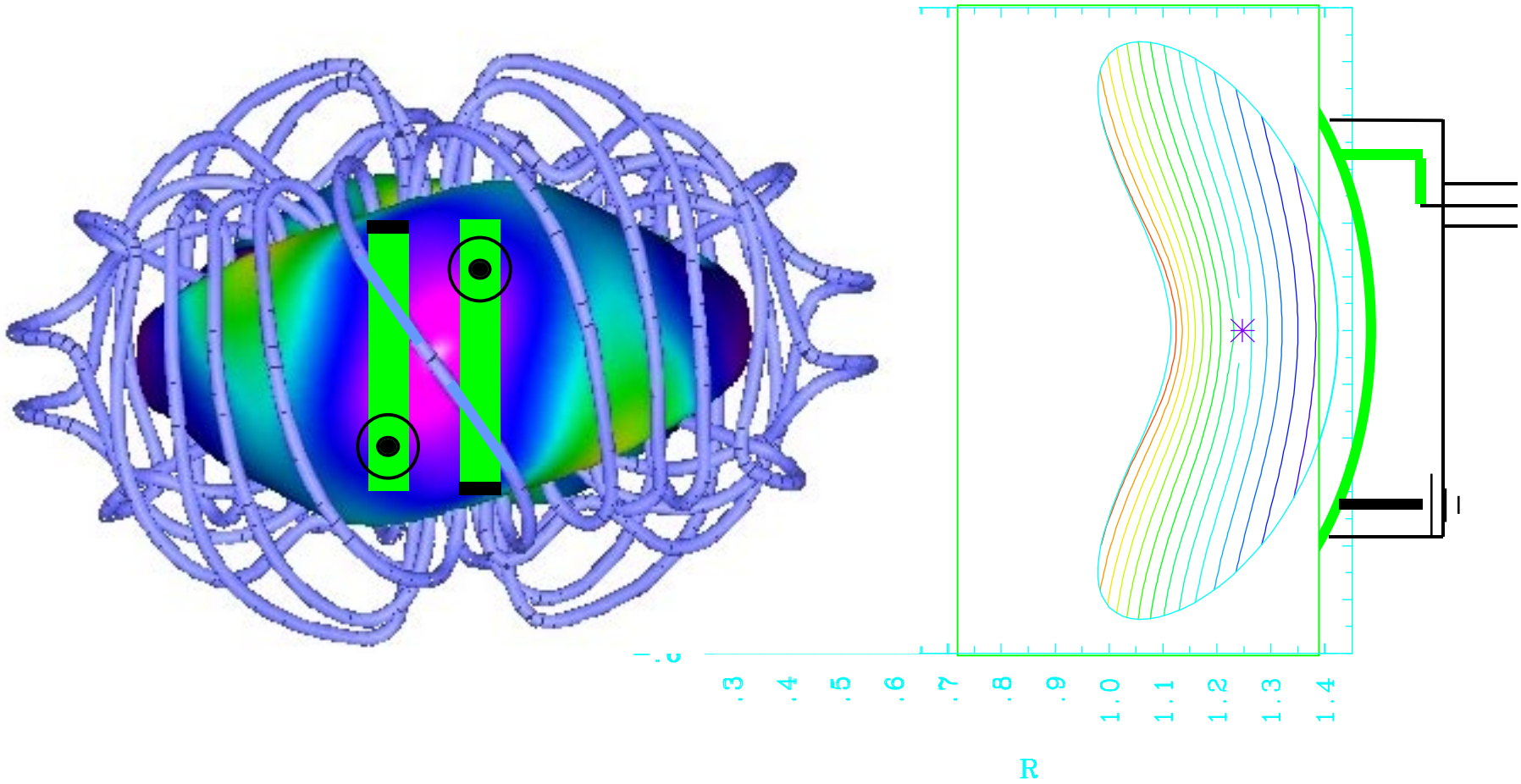
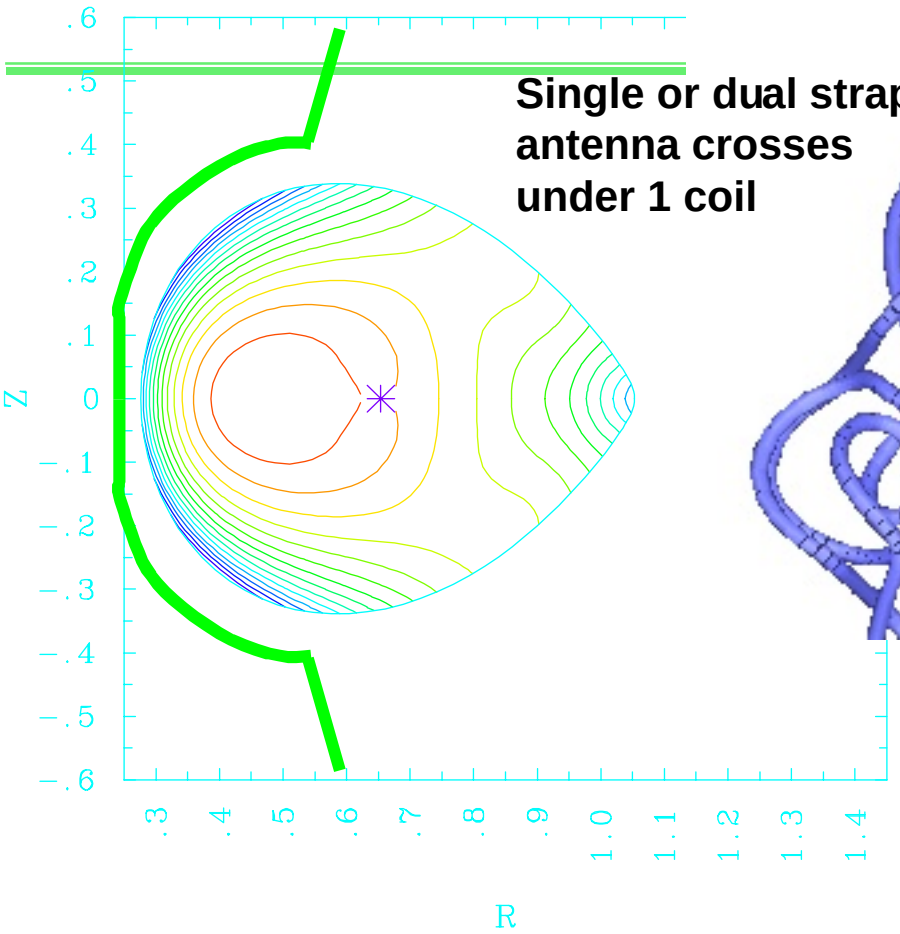

Hubble
Spirograph

Low Field Side Antenna

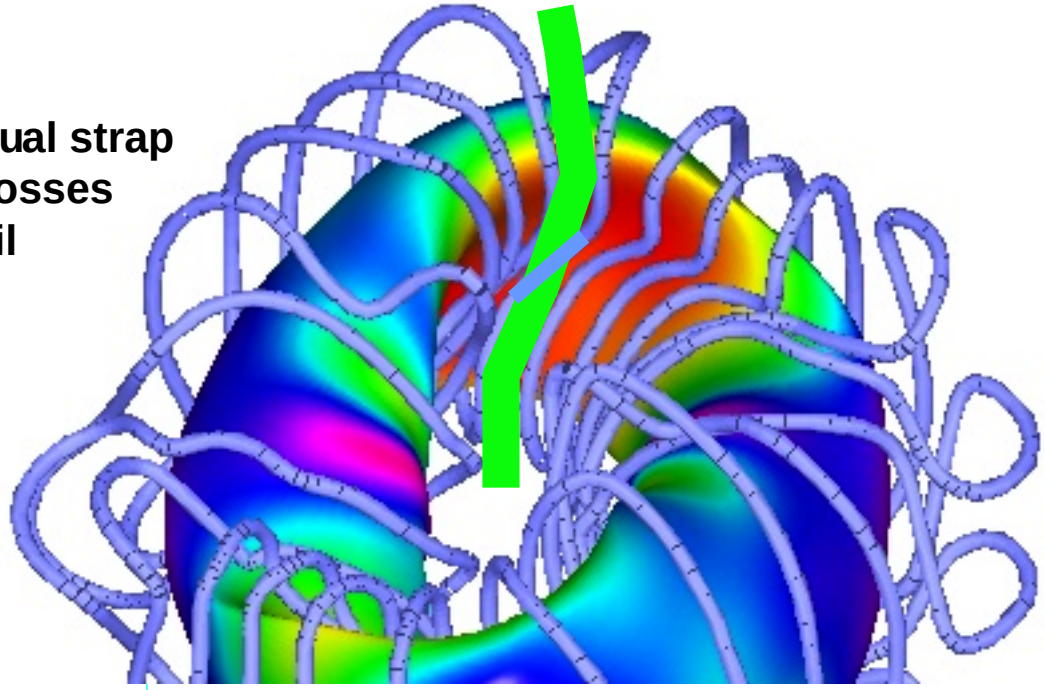


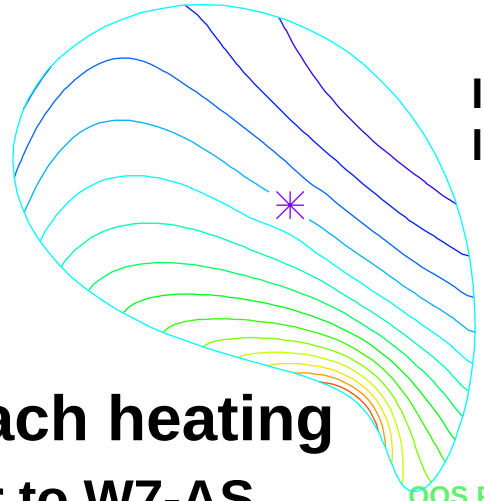
Minority, FW & HHFW heating

LHD/QOS Style High Field Side Antenna



Single or dual strap antenna crosses under 1 coil





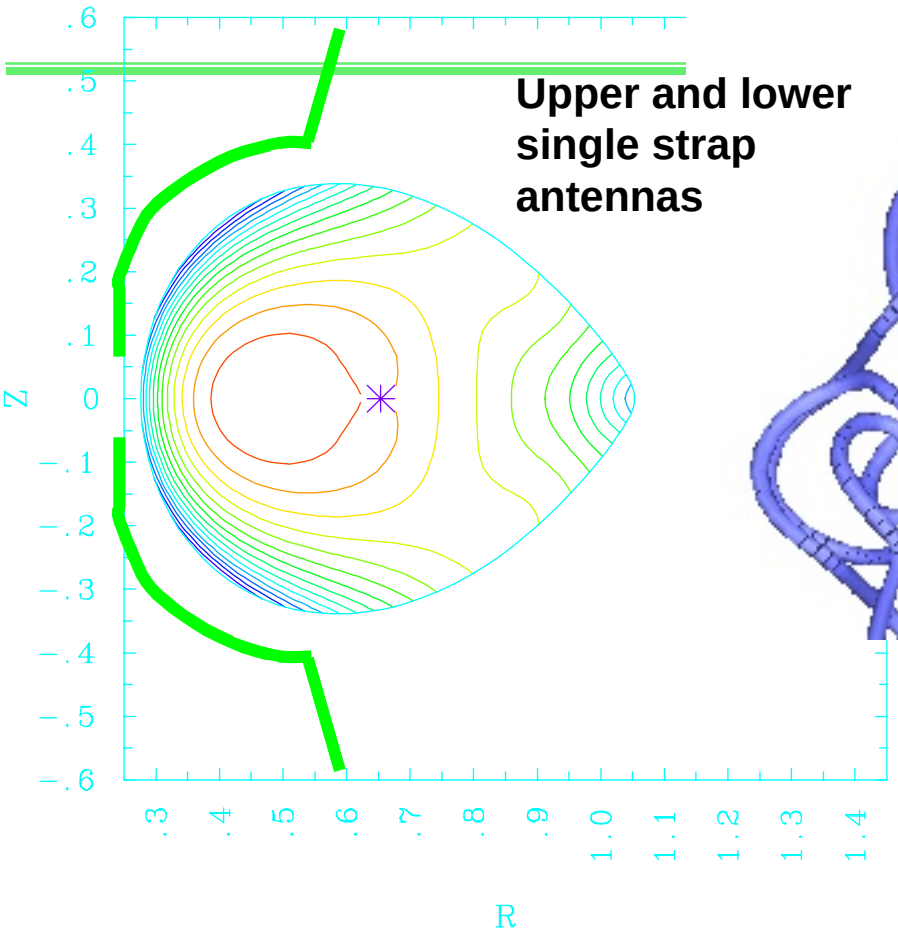
ICRF propagates to lower field region

Minority, Mode Conversion

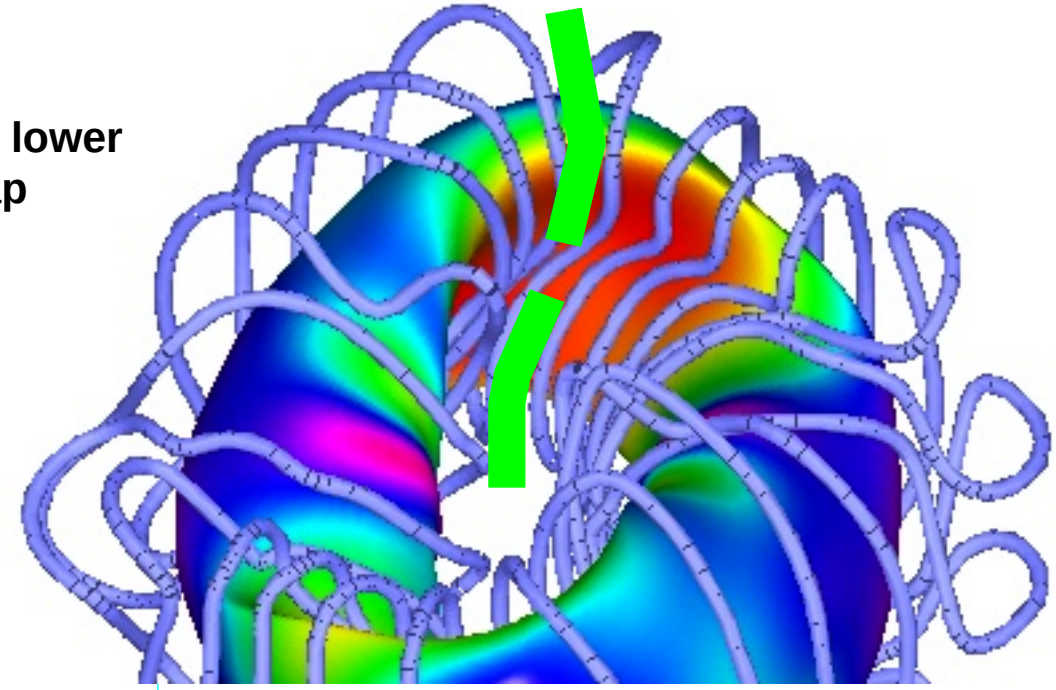
& Beach heating

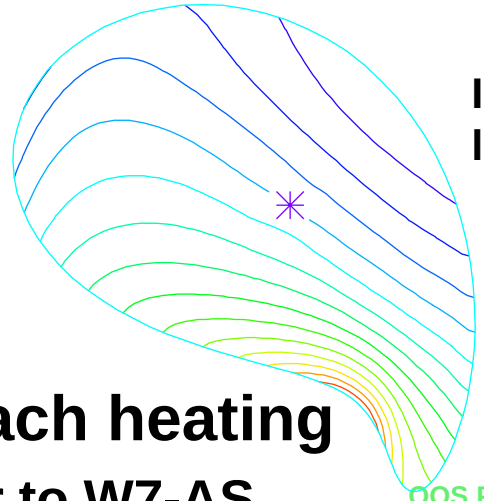
similar to W7-AS

LHD/QOS Style High Field Side Antenna



Upper and lower single strap antennas





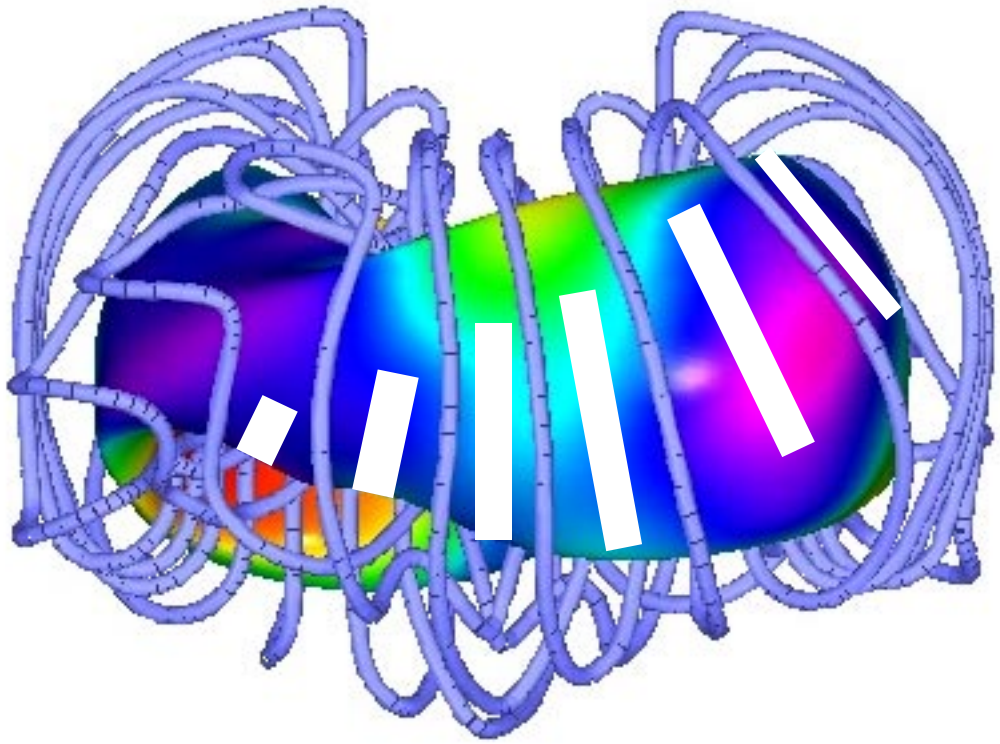
ICRF propagates to lower field region

Minority, Mode Conversion

& Beach heating

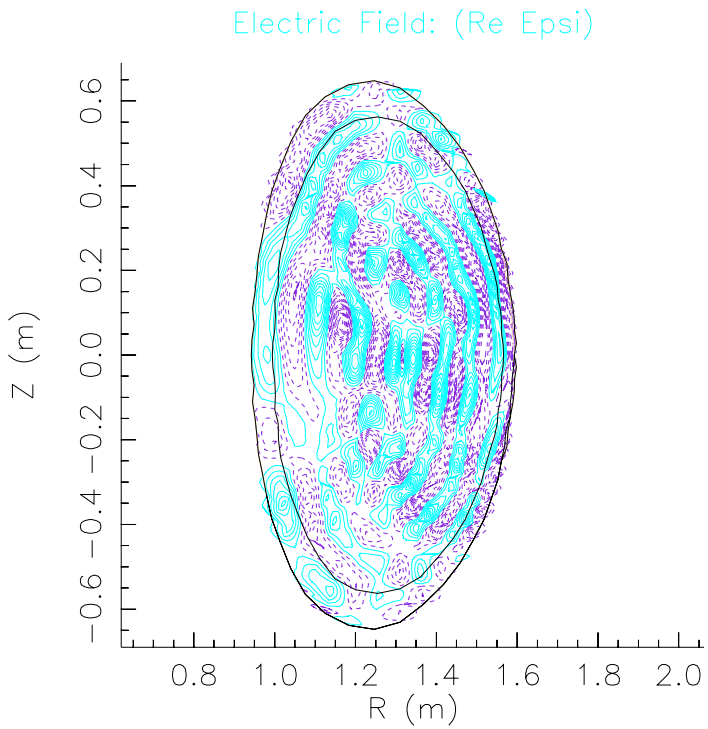
similar to W7-AS

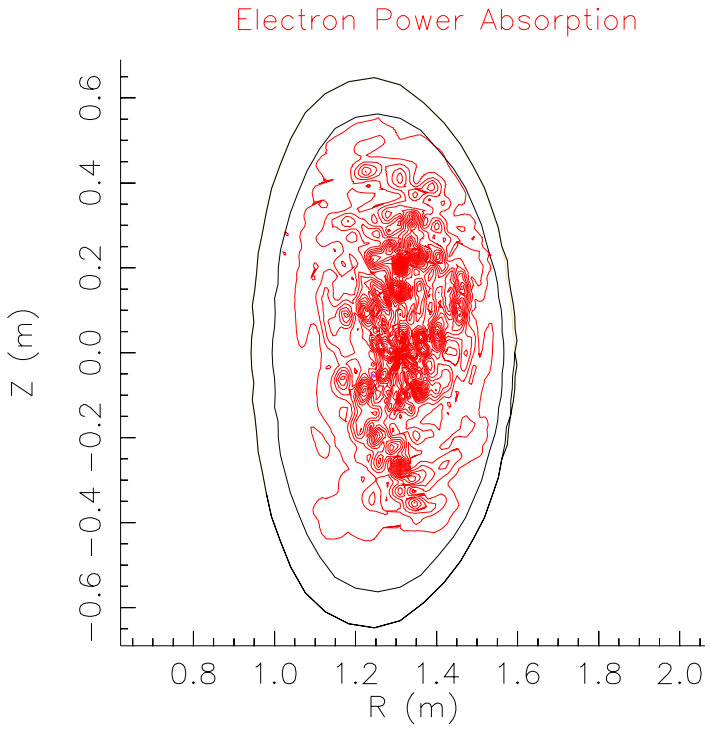
HHFW heating & CD Array



1 antenna strap between each coil

HHFW Absorption 1T 1% beta 60 MHz





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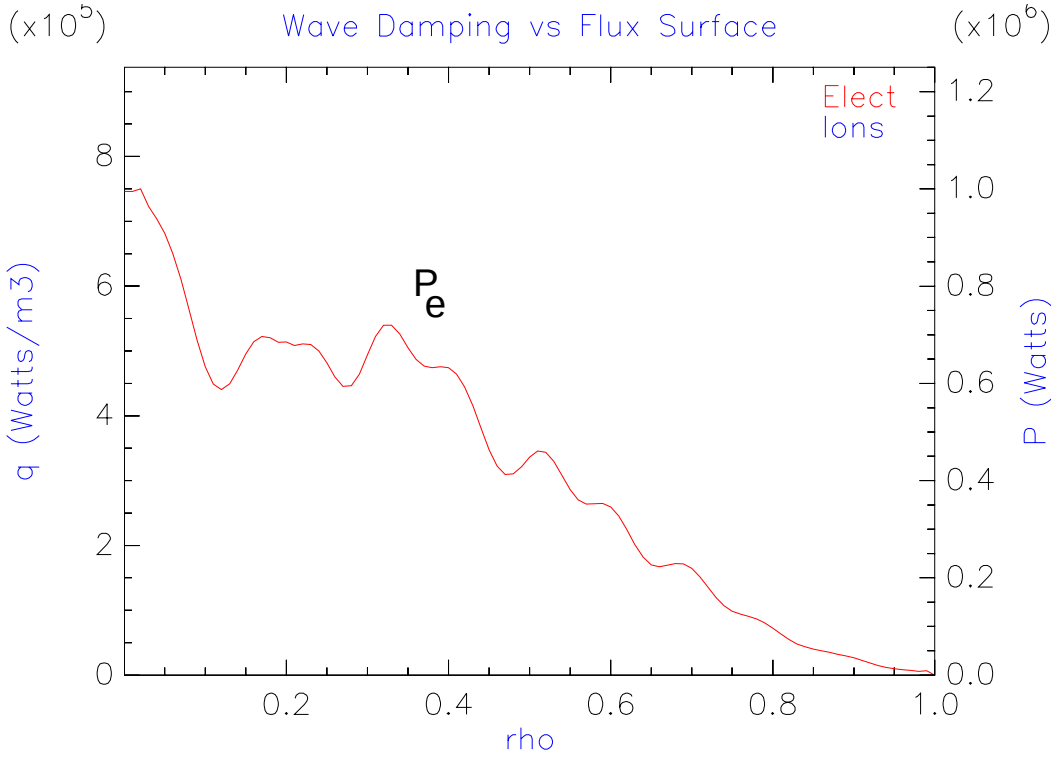
HHFW Absorption 1T 1% beta 60 MHz



Fred Jaeger

Summary

- **QAS & QOS offer new opportunities in ICRF, LH and ECH**
- **ECH will be a mainstay, EBW is also an option**
- **Open issues**
  - **Electron or ion heating?**
  - **Single pass absorption of HHFW or DEH**
  - **ICRF antenna size and directivity (?)**
  - **LH frequency and port size**
  - **Others**
- **ICRF is successful on similar sized stellarators**
- **Access and conditions look favorable**
  - **Several possible ICRF antenna designs**
    - **High field side antennas may be possible similar to LHD/CHS, W7-AS**
    - **Low field side antennas similar to NSTX**
  - **Mode conversion, magnetic beach, & HHFW look possible**