ICRH on W7-AS

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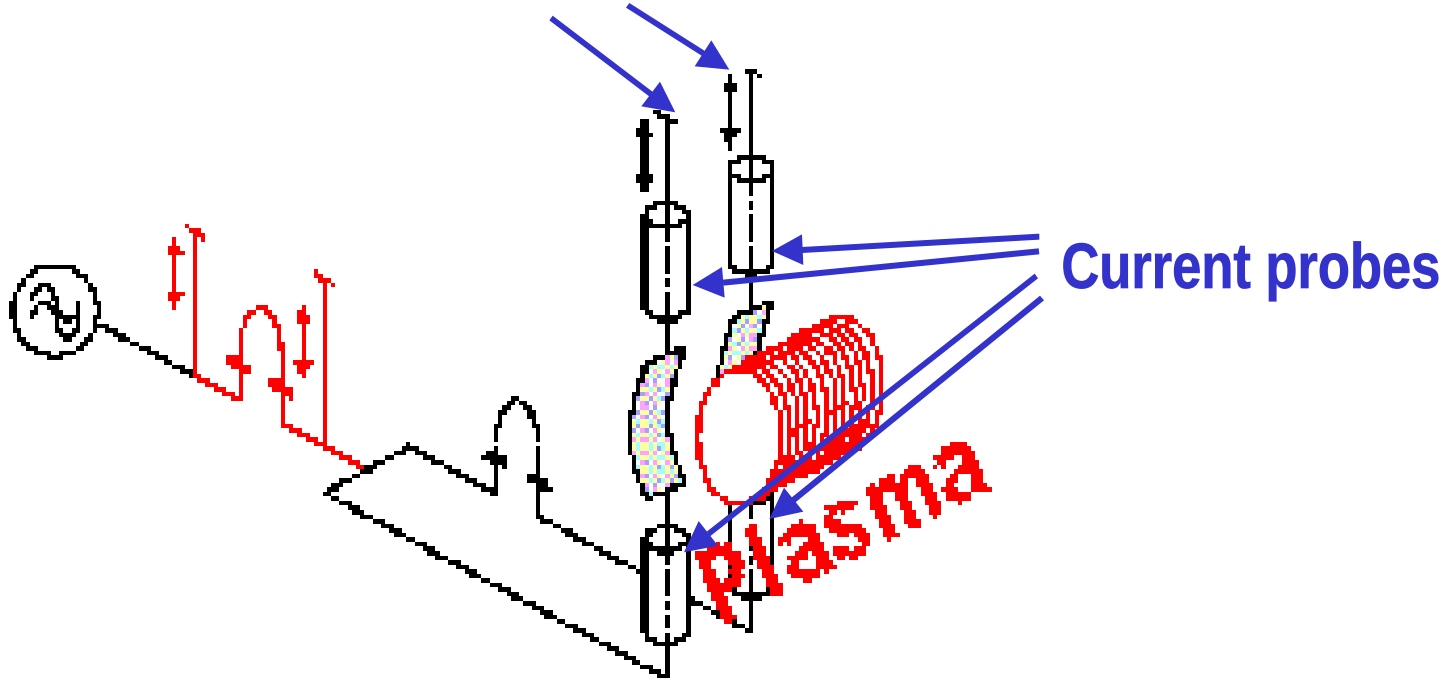
RF System

2 Generators:	34 < f < 74 MHz (35 -110 MHz nominal)
	δf = 100KHz
	50 kW cw
	1.2 MW for 10 sec (2 MW nominal)
Operation:	only one generator used
	maximum pulse duration 1 sec
	time between plasma pulses 7 min
Matching:	2 stub tuners with Δl=2500mm
Transmission lines:	50 Ω
	9 1/8" (outer) under 3 bar dry air in unmatched section, 12 m.
	6" under 0.5 bar in matched section, 120m
Vacuum feed through:	50 Ω, 0.8m, p< several 10^{-7}
Active cooling:	none

Antenna setup

Most W7-AS antennas do not have a short inside the vacuum vessel.
→ Resonant termination with stub tuners.



Proper setting of shorts checked with current probes at equal distances from antenna in pressurized TLs.
Typically phase between antenna straps set to 180° with TL extension.

Conditioning

Multi-pector conditioning:

with 1 kW amplifier of antenna region and vacuum feedthroughs for a few
hours after a torus vacuum break.

Generator conditioning:

•"burning off of arcing spots"
2 msec pulses with average power of 1 kW up to 60 kV_{peak} in TL.
Arc detection derived from absolute value of reflected power.
Generator switch-off time 2-5 μsec.
Max. standing voltage reduced by boronization, but quickly recovered.

•"Degassing of antenna and vacuum feedthroughs"
RF pulse extension up to 0.5 sec.

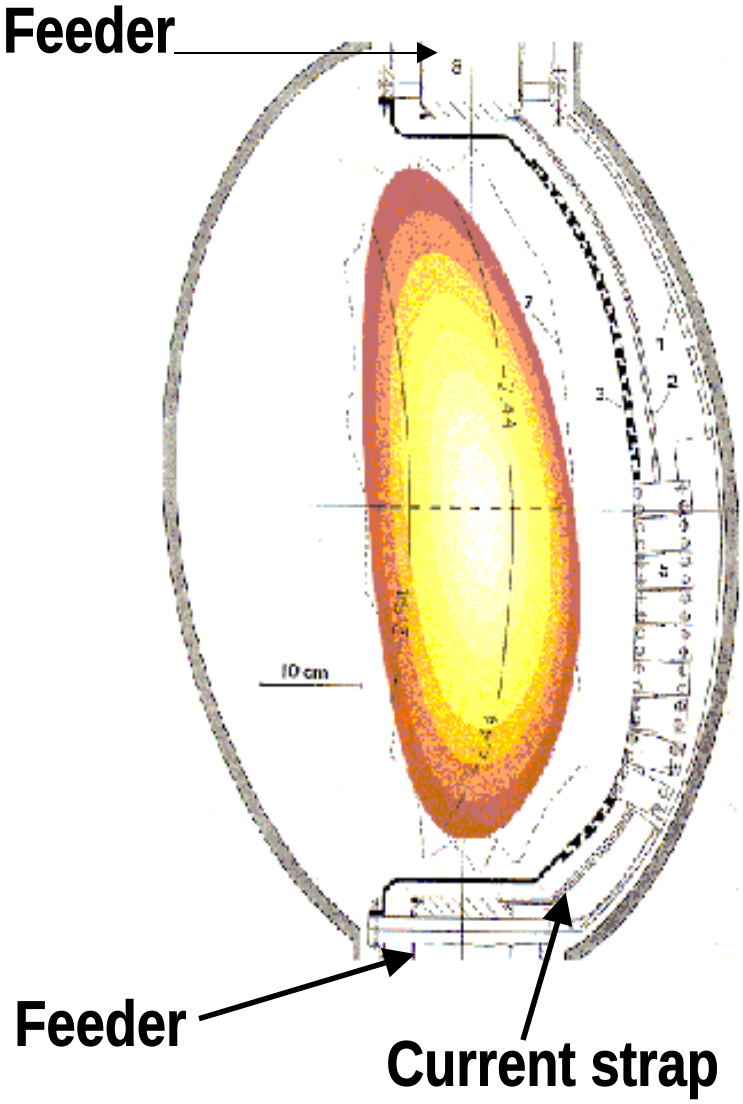
Problems and Solutions

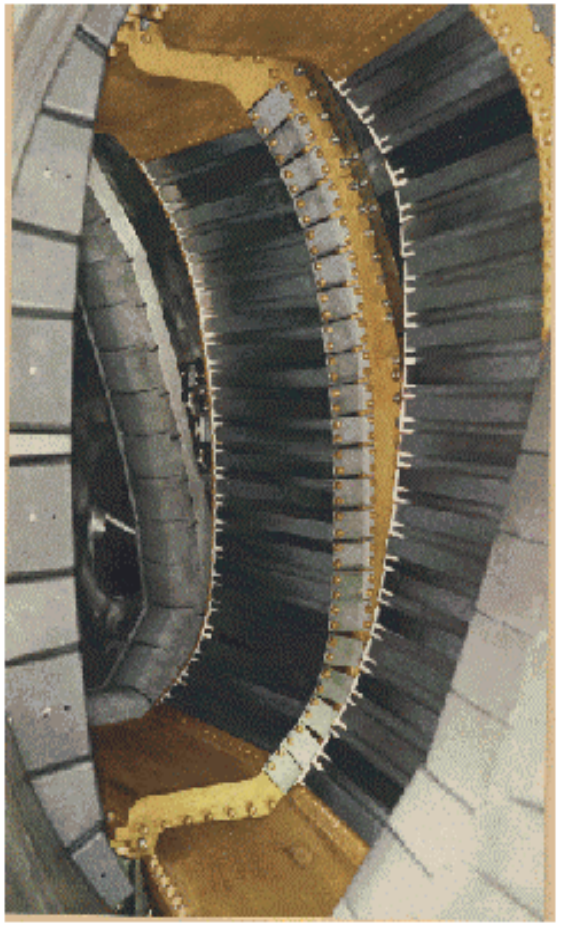
High antenna loading with plasma.	Prevent any field line connection between antenna feeders and tenuous plasma.
Generator oscillations	Replace copper inner conductors of a section of 8m of the matched TL with steel. Simply changing the length of TL did not help.
Conditioning progress slow	Reduce generator switch-off time to less than 10μs.

Antennas in W7-AS

	Antenna 1	Antenna 2	Antenna 3	Antenna4
Location, toroidal angle	LFS, 0°	HFS, 0°	HFS, 0°	“HFS”, 36°
Type	2 current straps	Multi-strap	2 current straps	2 current straps
Location of short	Outside torus	Inside and outside	Outside torus	Inside torus
Material current strap / feeder	Stainless / stainless	Stainless/ Stainless	Stainless/ stainless	Stainless/ Copper
Poloidal length of active area	50cm	40cm	50cm	32cm
Faraday screen	Horizontal, opaque	Horizontal, 50% open	Aligned, 50% open	none
Feeders: Z0 Outer →	30 Ω 25cm	30 Ω, 25cm	30 Ω 25 cm	30 Ω 10 cm
Smallest (largest) distance to standard LCFS	8 cm (15 cm)	7 cm (9 cm)	5 cm (5 cm)	5cm (5cm)
Toroidal width over all	85 cm	100 cm	80 cm	22 cm

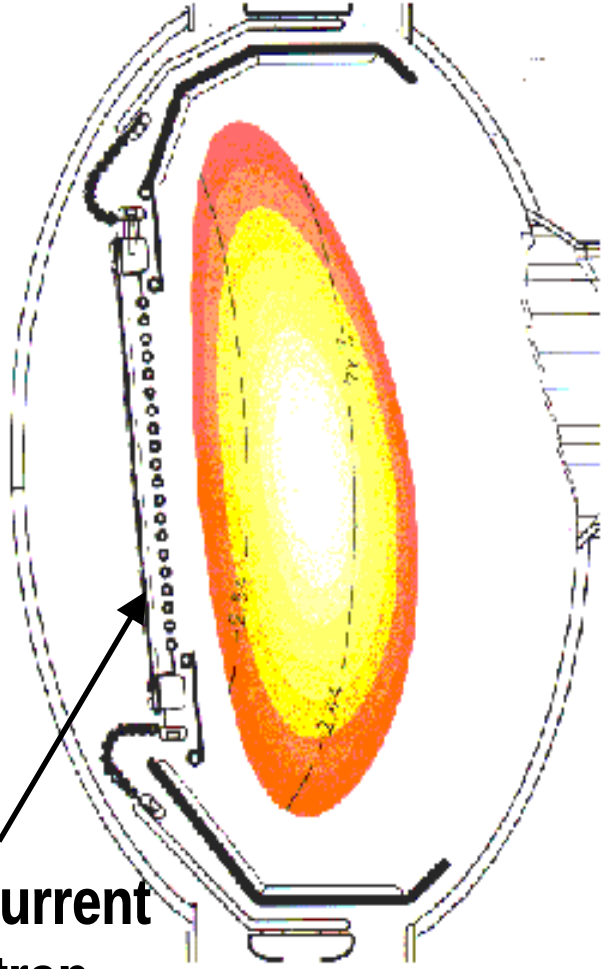
Antenna 1





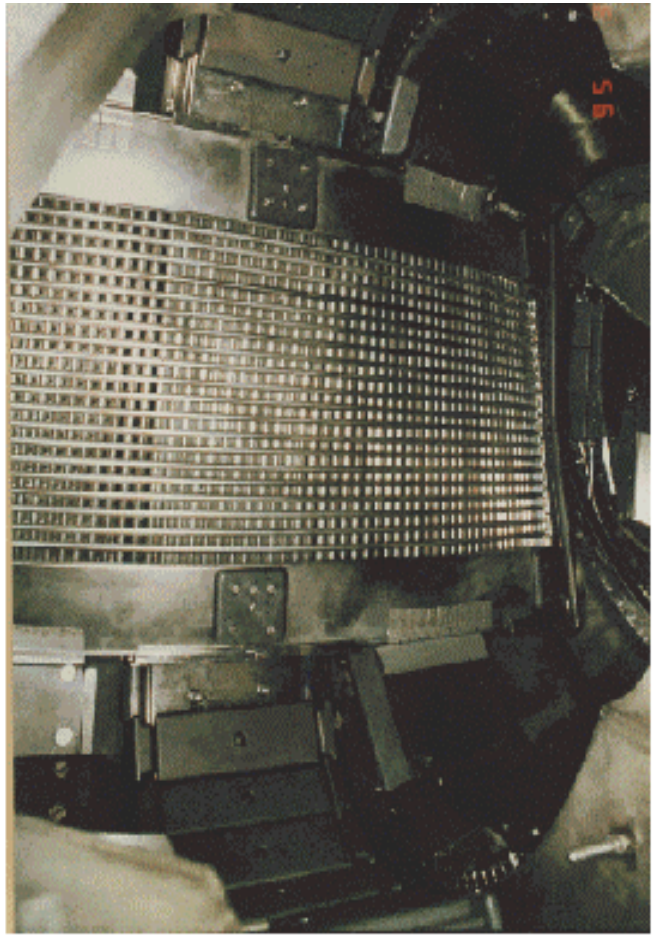
Antenna 2

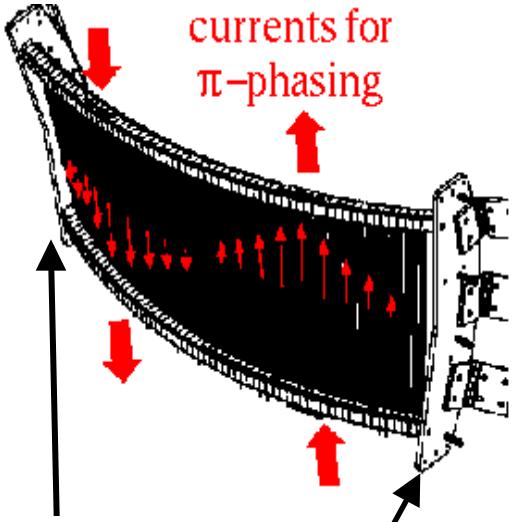
Feeder



Current strap

Feeder



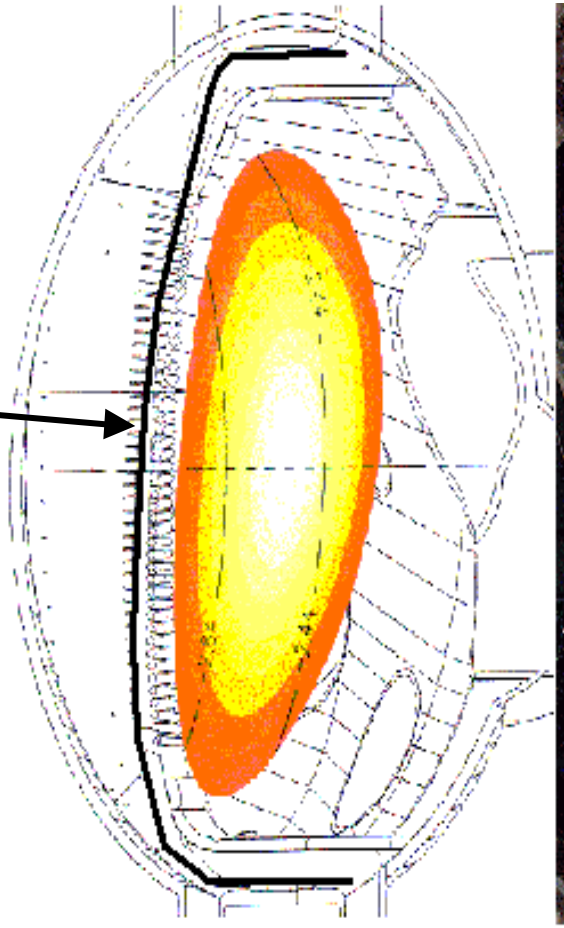


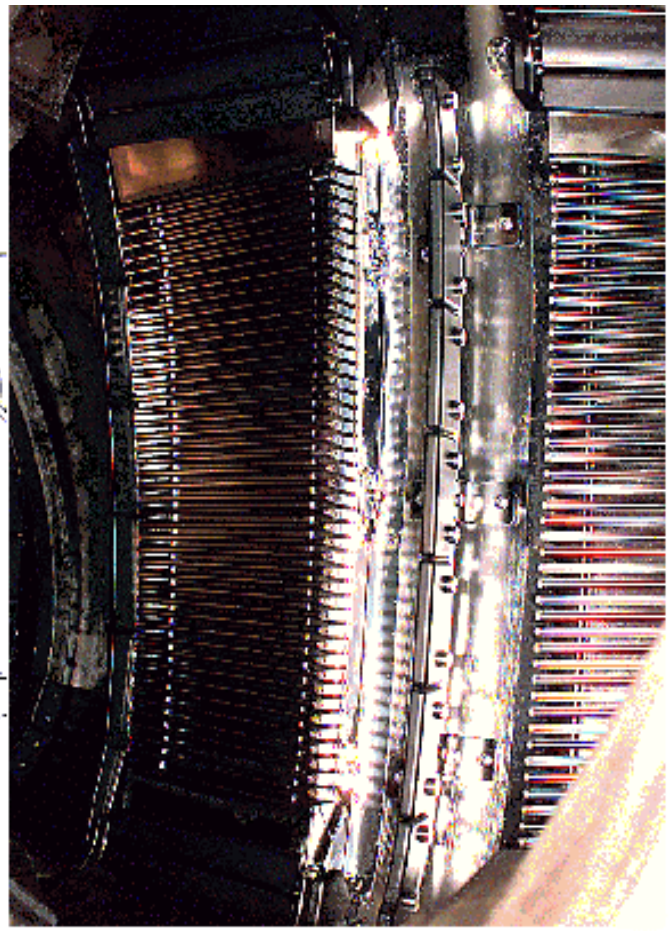
Connected to torus wall

Antenna 3

Feeder

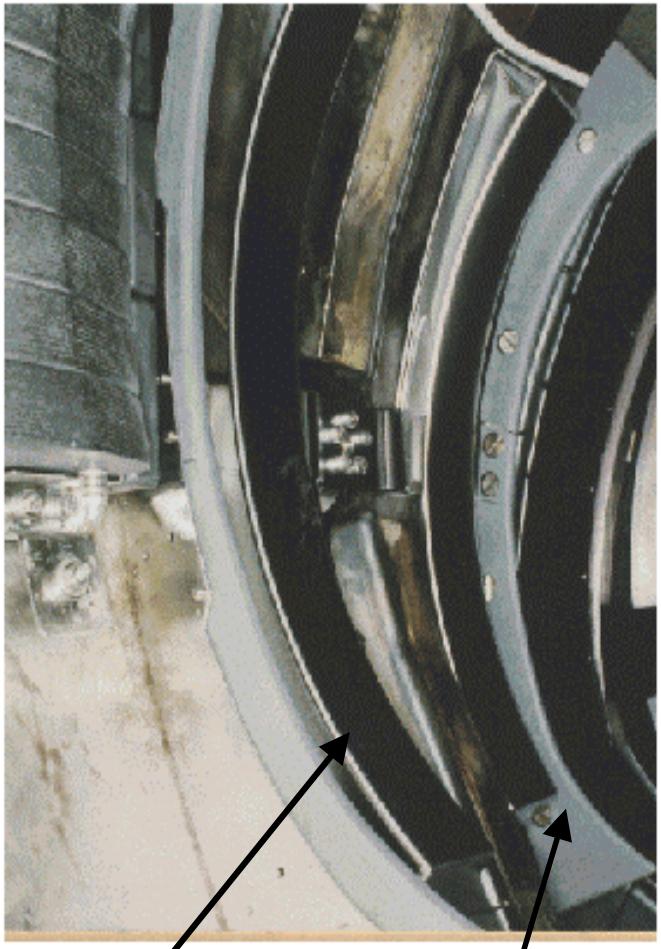
Current strap





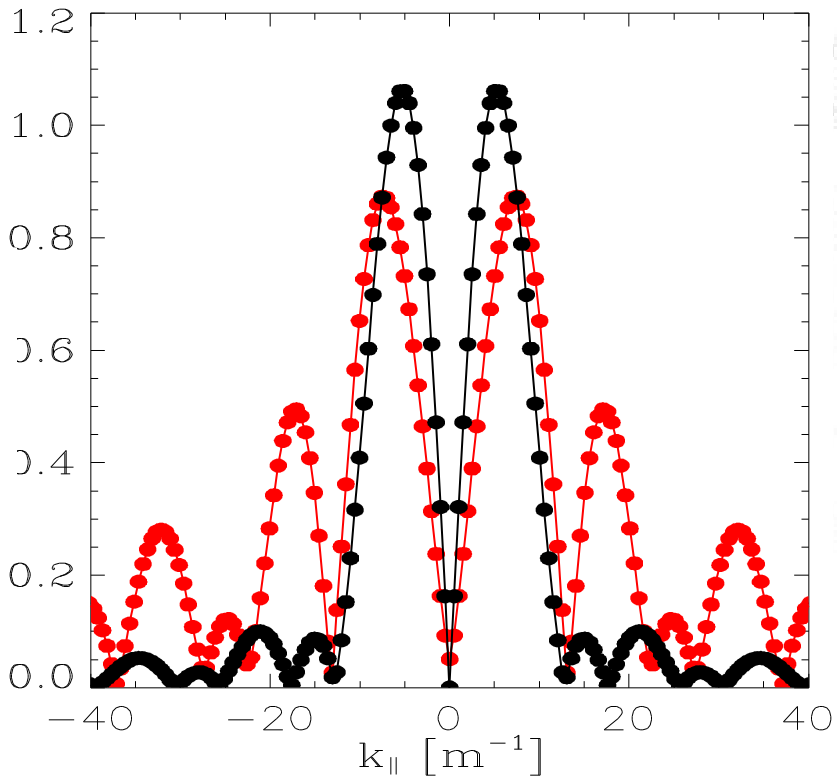
Feeder

Antenna 4

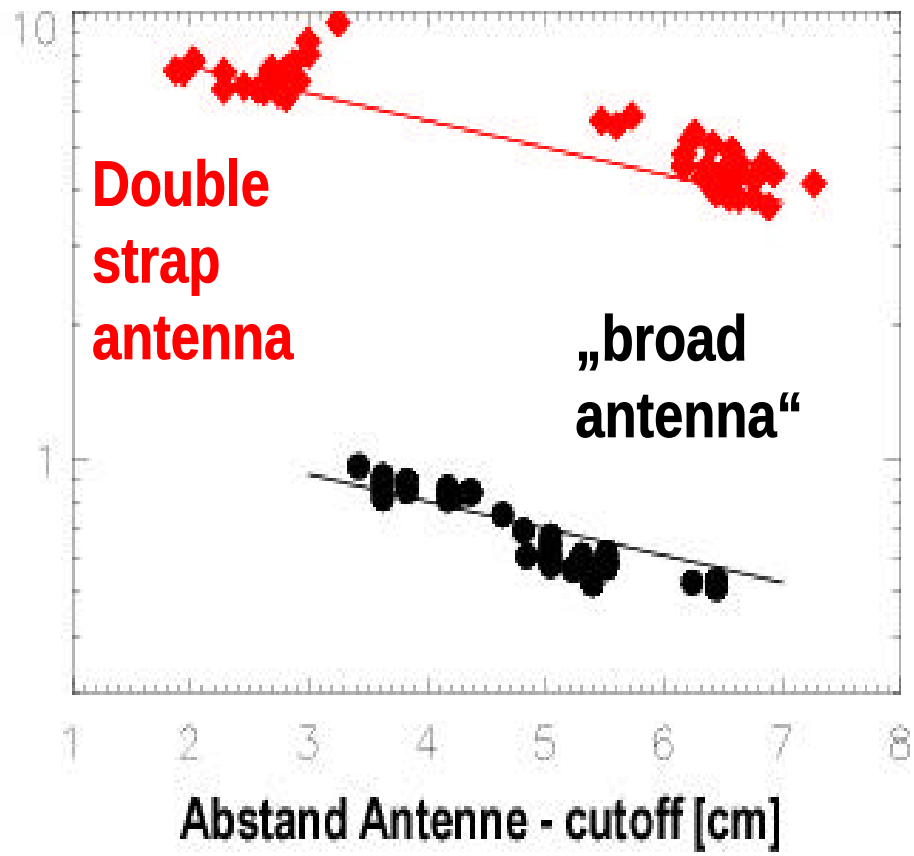


Properties Antenna 2 and 3

Spectrum $\{\tilde{B}_{\omega,k}\}_{\parallel}$



Antenna resistance with plasma [Ω]



Maximum at $k_{\parallel}$ = 6m^{-1}

Decay length ik $\approx k_{\parallel}$

Heating Efficiency

heating efficiency η $\dfrac{\text{absorbed power}}{\text{launched power}}$

Done with
modulation experiments

$$\frac{d(W_0+\tilde{W})}{dt} = -\frac{(W_0+\tilde{W})}{\tau_E(P)} + (P_0+\eta P_{rf}\cos(\Omega t))$$

$$\frac{\tilde{W}}{\tilde{P}_{RF}} = \frac{0.5*\eta}{\frac{3}{4}\frac{1}{\tau_{E0}}+i\Omega}$$

mit Annahme $\tau_E \quad P^{-0.5}$

switch on/off experiments

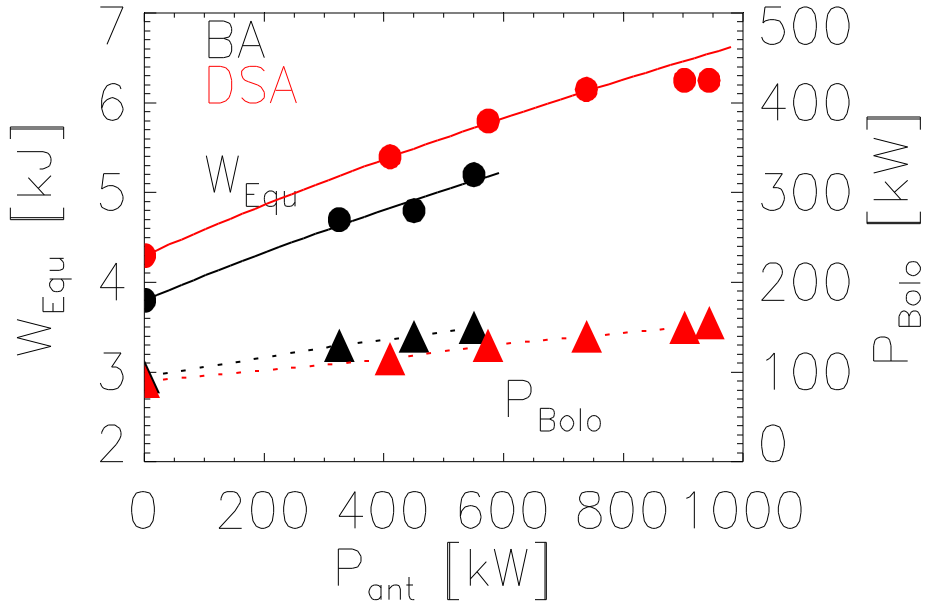
$$\frac{dW}{dt} = 0 = -\frac{W_0+\Delta W}{\tau_E(P)} + (P_0+\eta P_{rf})$$

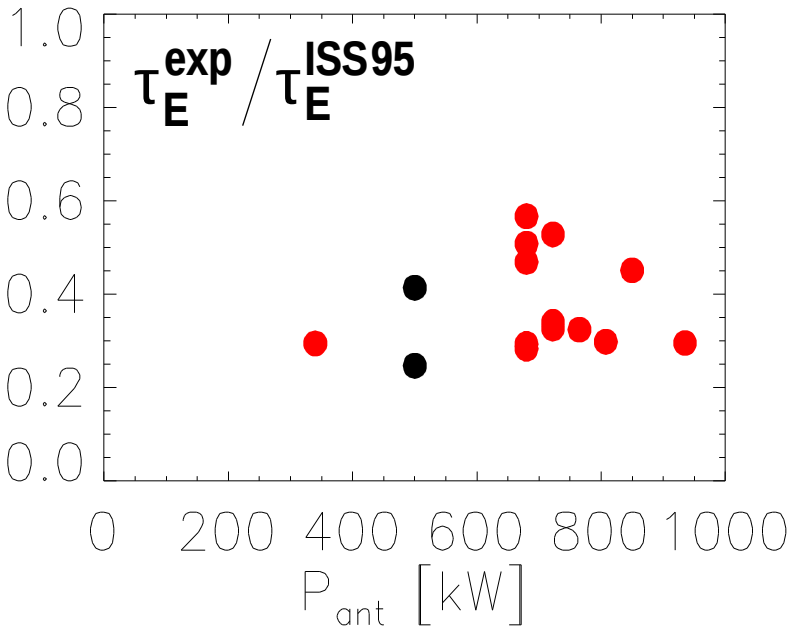
yield about the same results.

2nd harmonic hydrogen heating

Braod antenna (#2)

NBI target plasma **Double strap antenna (#3)** **ICRH only**



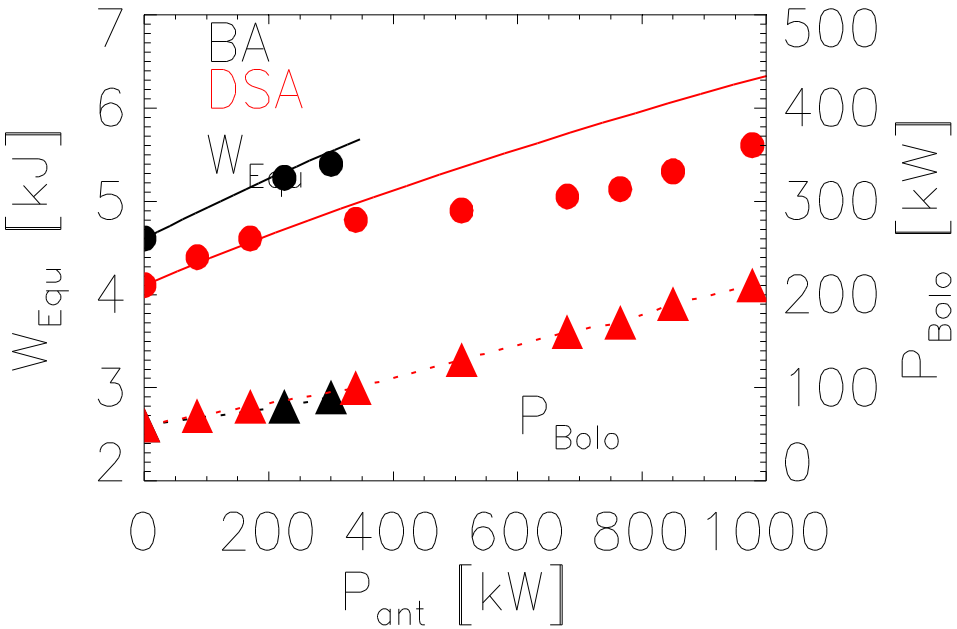


Heating efficiency: η **0.7**

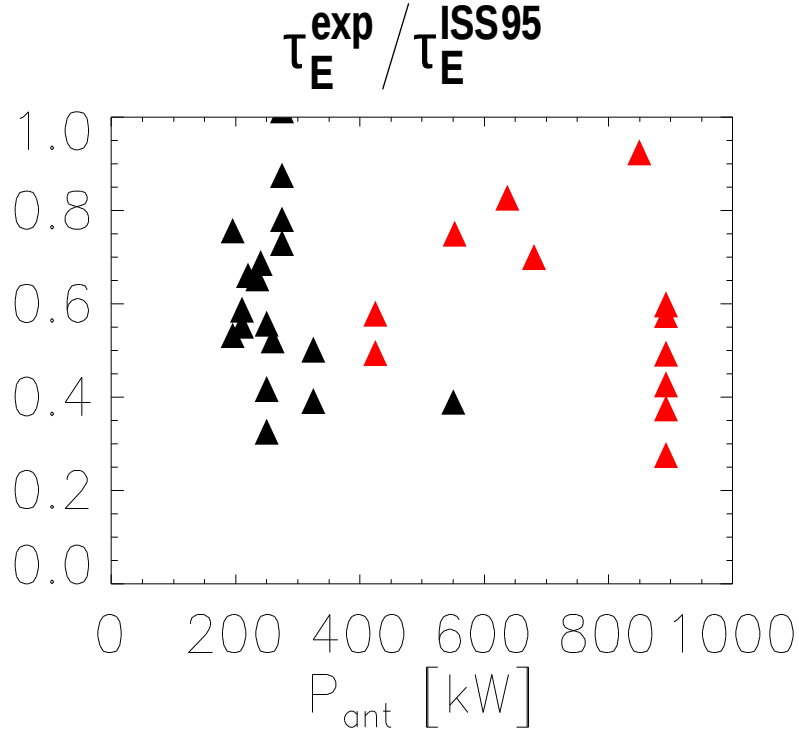
$$\tau_E^{ISS95} = 0.115 \cdot a^{2.21}[m] \cdot R^{0.74}[m] \cdot B^{0.73}[T] \cdot \lambda^{0.43} \cdot n^{0.5}[10^{19} m^{-3}] \cdot P^{-0.54}[MW]$$

D(H) minority heating

ECRH Target plasma



ICRH Plasma

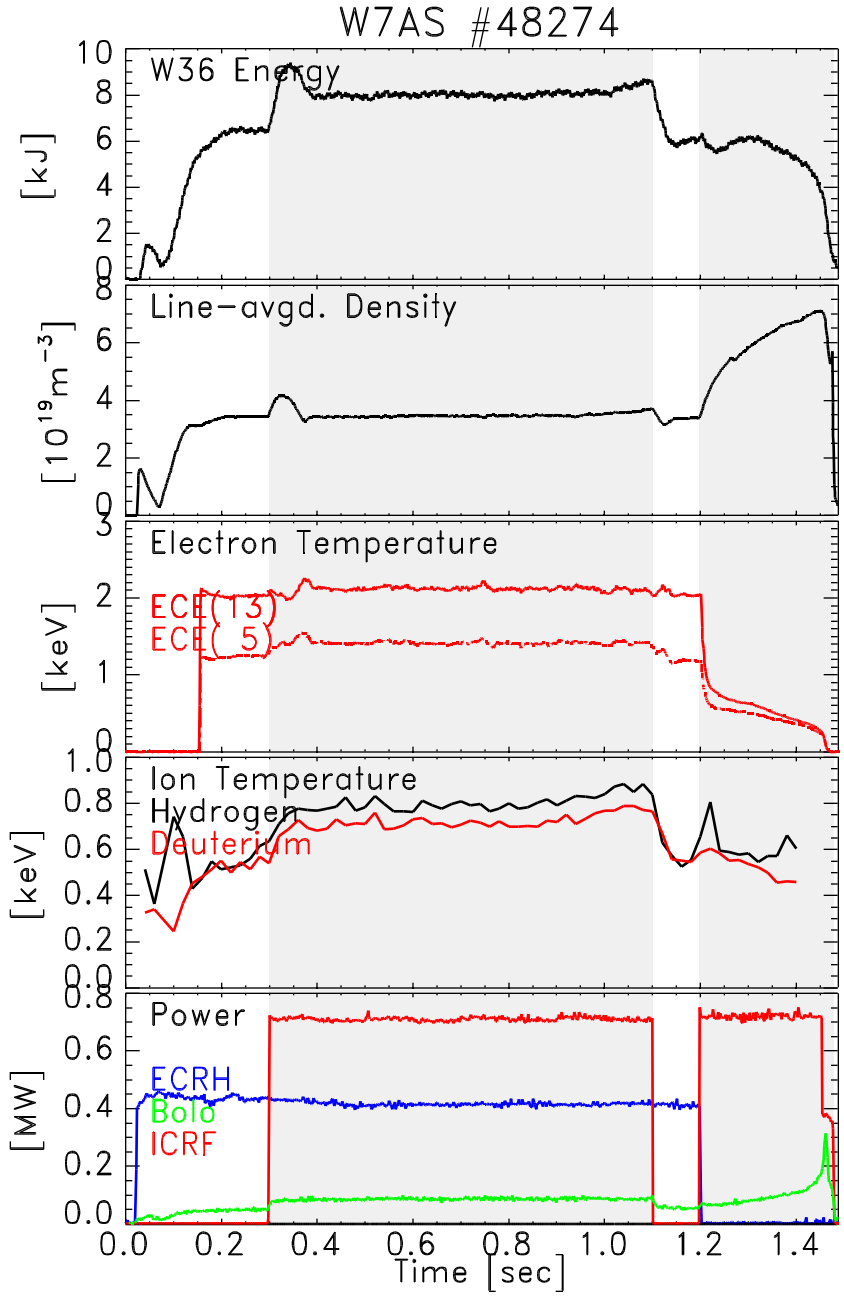


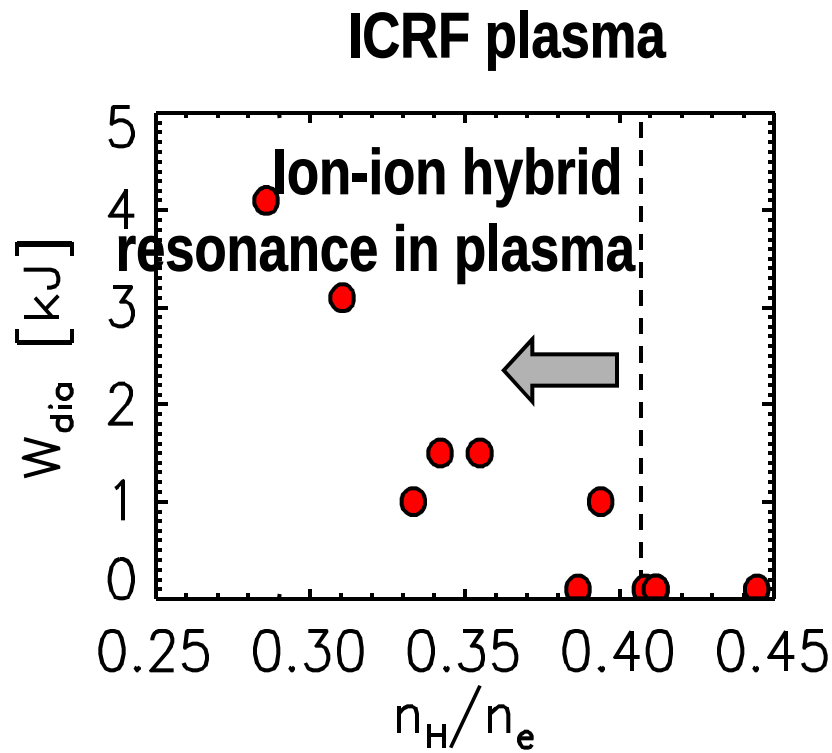
Heating efficiency: η 0.8

Braod antenna (#2)

Double strap antenna (#3)

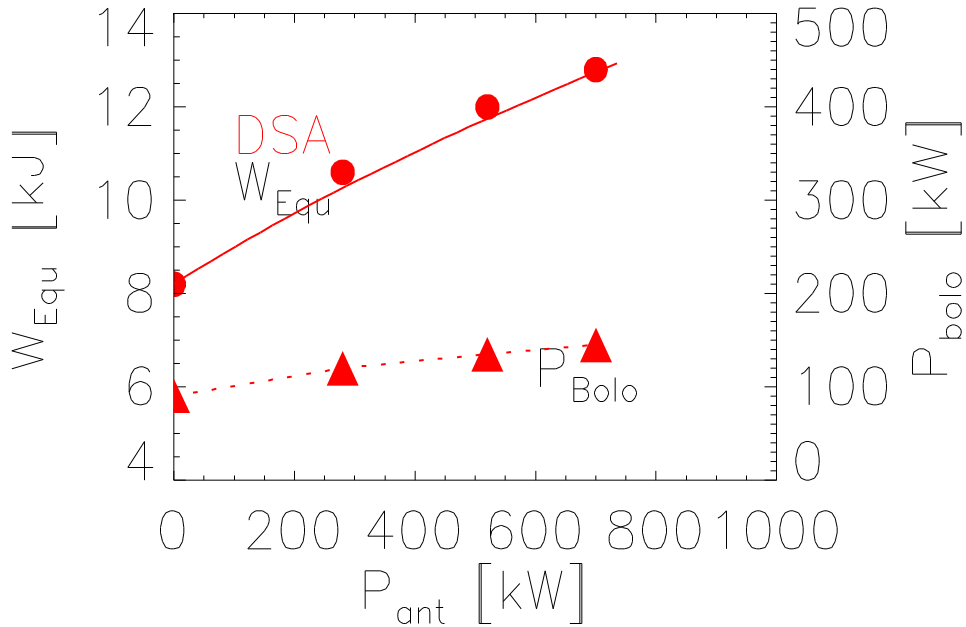
D/ H mode conversion heating





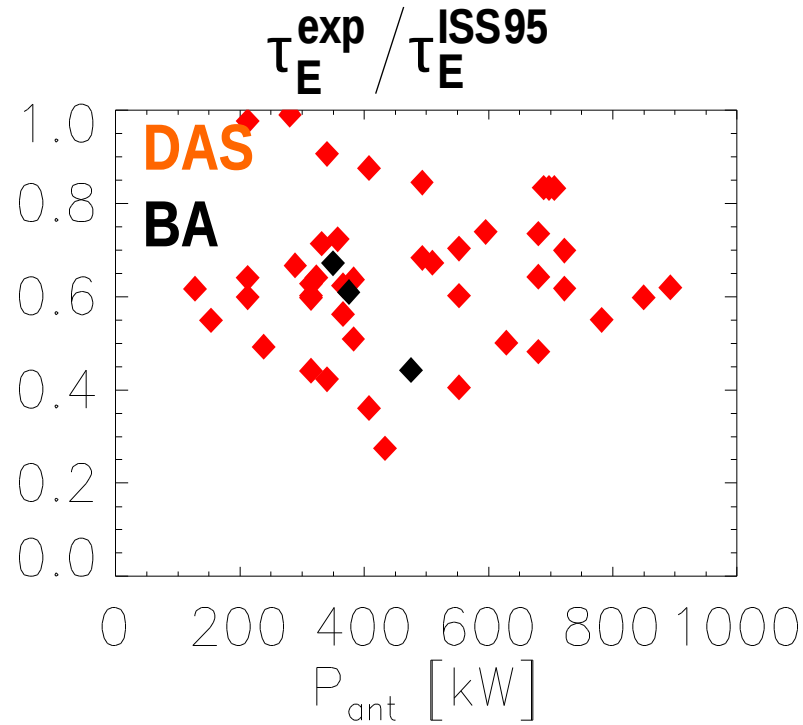
D/H mode conversion heating

ECRH Target plasma



η **0.8**

ICRH Plasma



Braod antenna (#2)

Double strap antenna (#3)

Antenna properties

	Antenna 1	Antenna 2	Antenna 3	Antenna4
Max. volt. in TL for vac. For 0.1 sec	30 kV ?	60 kV	60 kV	40 kV
Max. volt. in TL with plasma for 0.5 sec	30 kV	Generator power limited	50 kV	10 kV
Vacuum resistance	0.25 Ω	0.7 Ω	0.7 Ω	0.2 Ω
Typ. plasma resistance	0.5 Ω	1.5 Ω	8 Ω	2 Ω
Maximum power / duration	140 kW / 0.4 s	800 kW / 1 s	1.2 MW / 1 s	200 kW / 0.01s
Heating efficiency	Radiation terminated	80%	80%	No effect
Phase between straps	0°, 180°	0°, 180°	0°-180°	180°
Heat. Eff. phase dependent?	no	weak	weak	n.a.
Boronized machine?	no	yes	yes	yes
Density increase?	yes	weak	weak	weak
Bolometric radiation increase?	strong	weak	weak	weak

Present Situation

Only antenna of type 4 installed in W7-AS due to divertor installation.
Plasma coupling very poor.
No heating experiments expected.

Planning for W7-X:

R=5.5m,<a>=0.5m
B_T<3 T, ECRH(140 GHz) and NBI
Island divertor

2 generators: 25 < f < 76 MHz, each: 1.5 MW cw, 2 MW pulse.
2 symmetric double strap antennas (perhaps resonant loop)
H x W x D = 80 cm x 80 cm x 12 cm
antennas radially movable by 12 cm.