FUSION ENERGY DIVISION

ICRF Plans for the Quasi Poloidal Stellarator

D. A. Rasmussen, E. F. Jaeger,
D. B. Batchelor, B. E. Nelson ORNL

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Plasma Heating Introduction

- **QOS offer new opportunities in ICRF, ECH/EBW**
  - **What are the options?**
  - **What heating, current drive, profile, or flow control is desired?**

- **Worldwide ICRF and ECH experience on stellarators can be applied to QOS**

- **QOS has the access and conditions for ICRF, ECH and EBW**

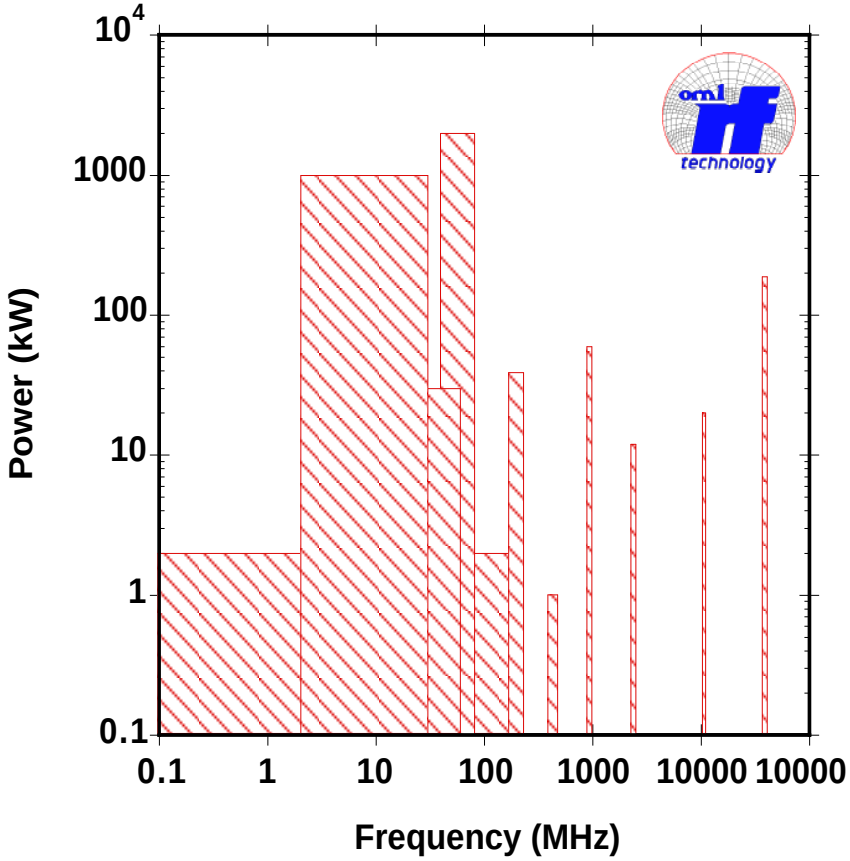
- **Heating of bulk electrons and ions at high beta is achievable**

Plasma heating introduction

- QPS offer new opportunities in ICRF, ECH/EBW
- Worldwide ICRF and ECH experience on stellarators can be applied to QPS
- QPS has the access and conditions for ICRF, ECH and EBW
- Heating of bulk electrons and ions at high beta is achievable
- We have developed a staged approach for heating electrons and ions (Baseline with backup options)

ICRF, ECH/EBW and LH Assets

Type of RF Heating	Power and Frequency Range
ECH/EBW	1.2 MW at 28 GHz, 0.3 MW at 27.7 GHz, 0.2 MW at 35 GHz, 0.6 MW at 53.2 GHz, 0.2 MW at 56 GHz
ICRF	1.5 MW at 40-80 MHz, 2 MW at 6-20 MHz
Lower Hybrid	1 MW at 2.45 GHz, 0.1 MW at 800 and 915 MHz



Heating strategy - Staged approach with backup options

- Heat electrons at modest density - ECH only
- Heat electrons at high density
  - High Harmonic Fast Wave into an ECH target
  - Low field, outside antenna

Baseline

- Heat ions and electrons at high density
  - Mode conversion into an ECH target or ICRF only
  - High field, inside antenna
- Heat bulk ions at high density
  - Beach heating, ECH an target or ICRF only
  - High field, inside antenna
- Heat electrons at high density/beta - EBW

Backup options

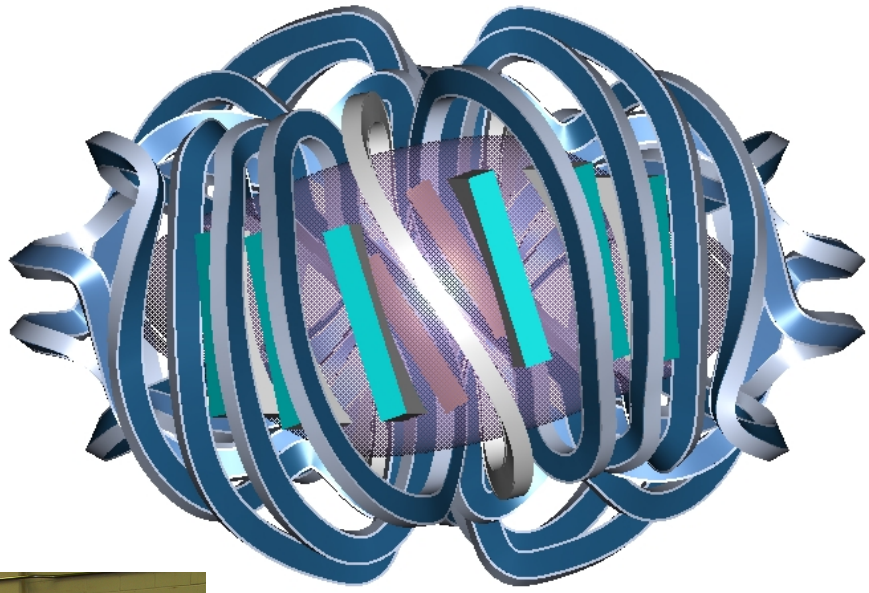
- Heat tail ions to study orbit losses
  - Minority heating
  - Low field, outside antenna
- Current drive and flow control
  - Fast wave, EBW or LH current drive

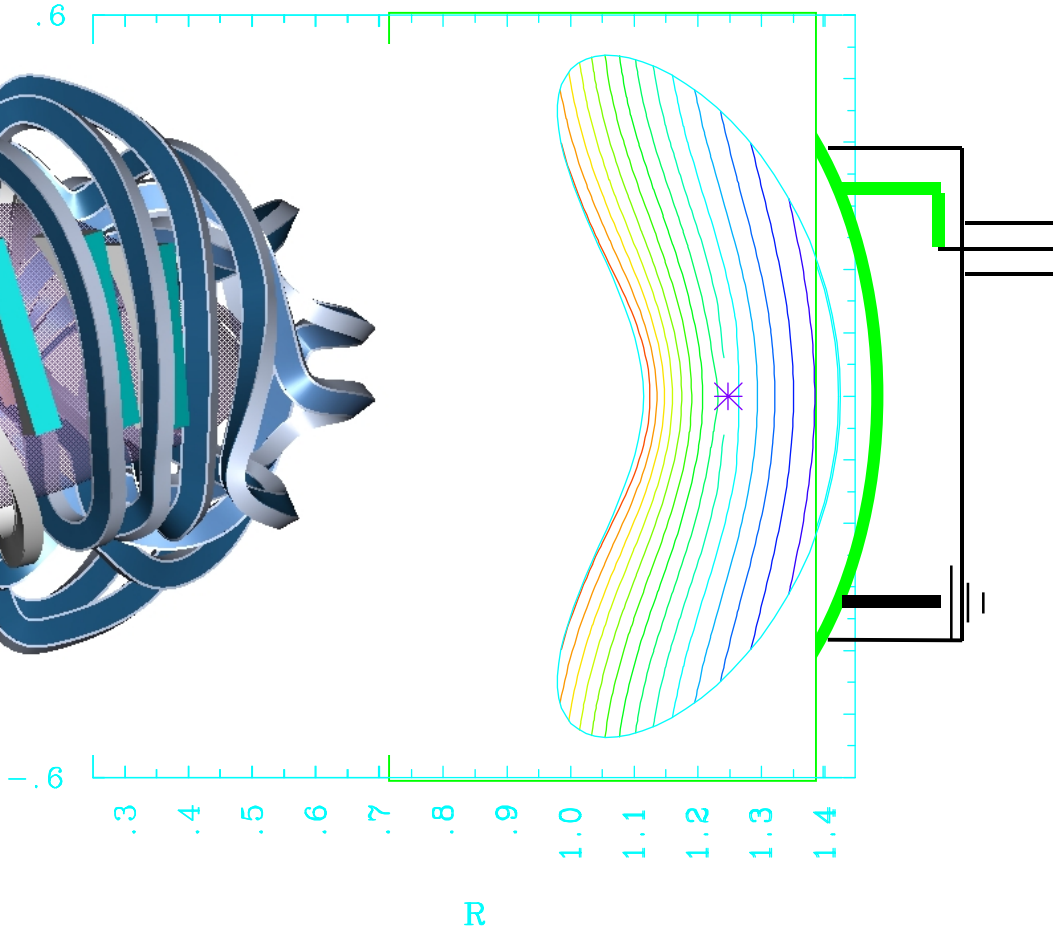
Physics Opportunities

ICRF options in priority order

- Direct electron or high harmonic heating (≥20 MHz)
  - FW and HHFW bulk electron heating
- Mode conversion heating (~ 15 MHz at 1.0 T)
  - IBW mode conversion at two-ion hybrid resonance layer
  - bulk electron heating
- Magnetic beach heating (< 14 MHz at 1.0 T)
  - bulk ion heating
- Minority heating (~ 14 MHz at 1.0 T ; He majority, H minority)
  - ~ 5 % minority (tail heating)
  - ~ 30 % minority (bulk ion heating)
- Current drive and flow control)
  - FWCD (≥20 MHz)
  - EBW CD (28 GHz)
  - LHCD (2.45 GHz, 915 MHz, 800 MHz)

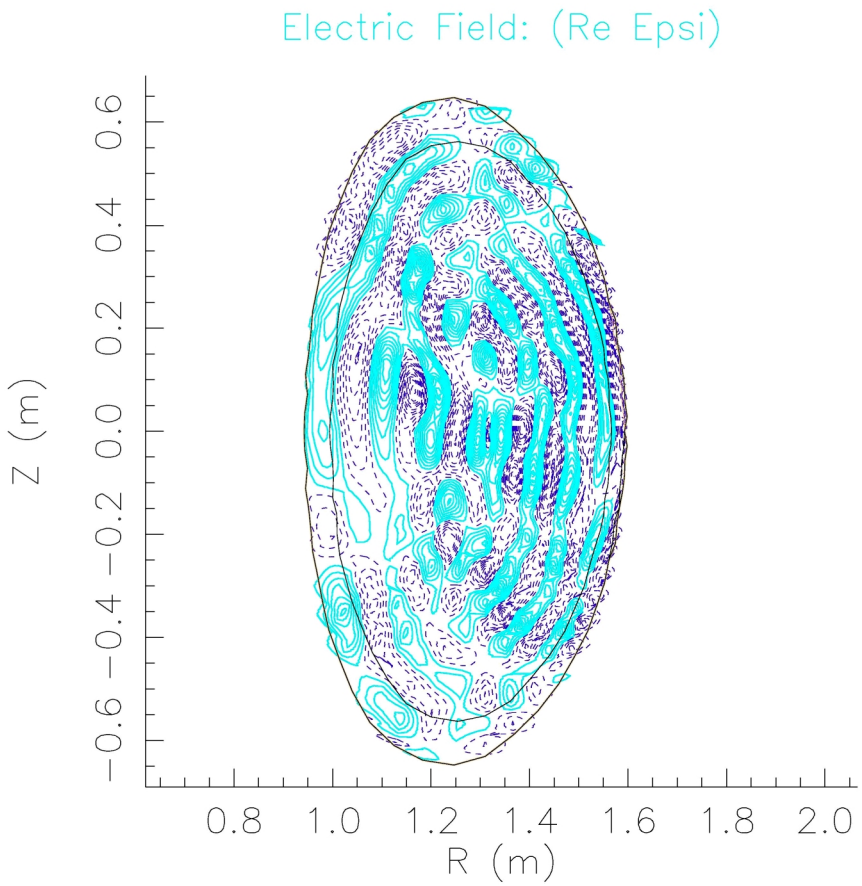
FW & HHFW and Minority heating

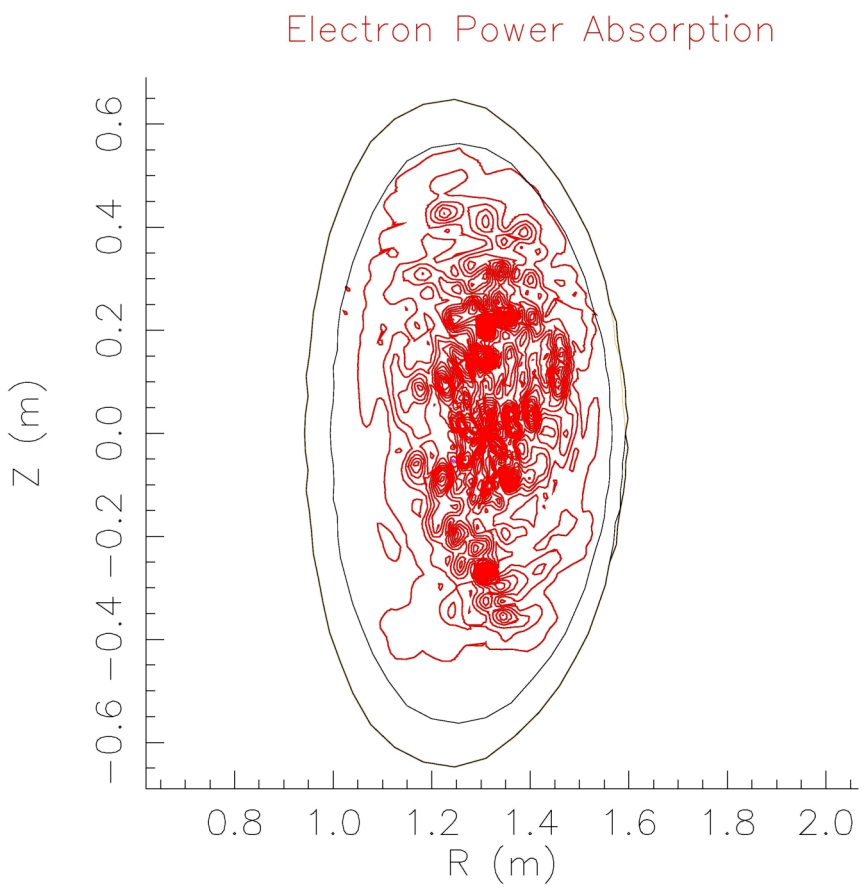




Low Field Side Antenna (NSTX style)

High Harmonic FW Absorption 1T 1% beta 60 MHz





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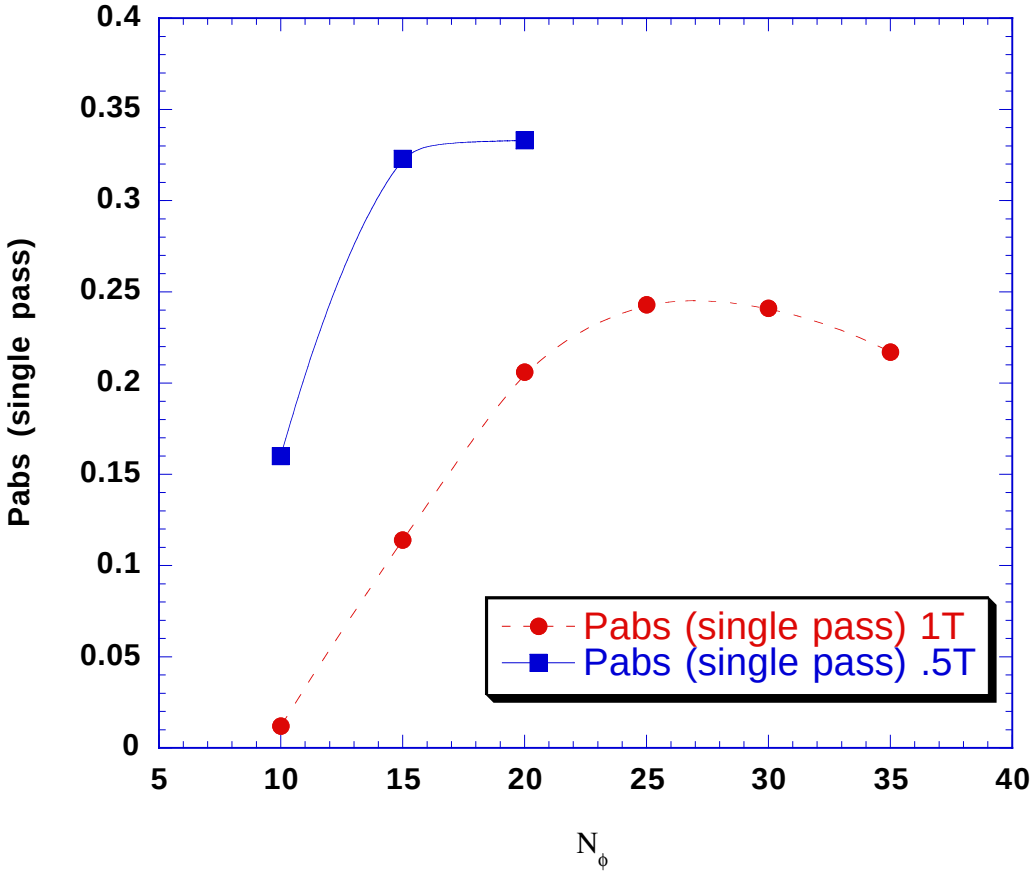
Single pass absorption calculations for HHFW look promising



ECH Target Plasma

ECH power perpendicular electron heating	28 GHz 4 @ 300KW ea. 2nd 28	53 & 56 GHz 4 @ 200KW ea. 2nd 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

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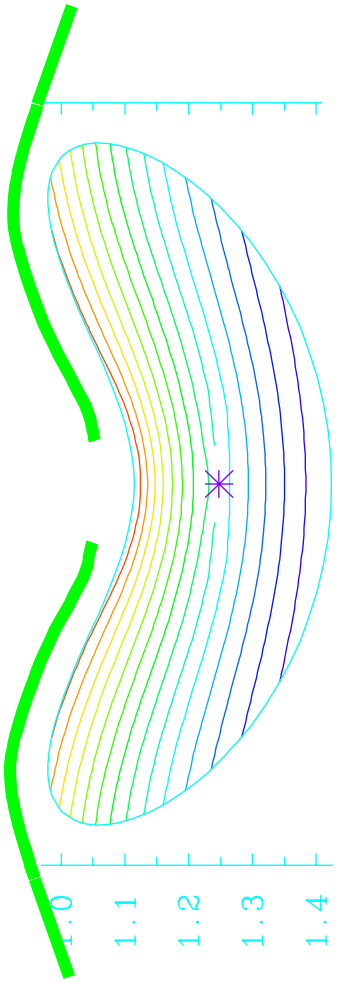
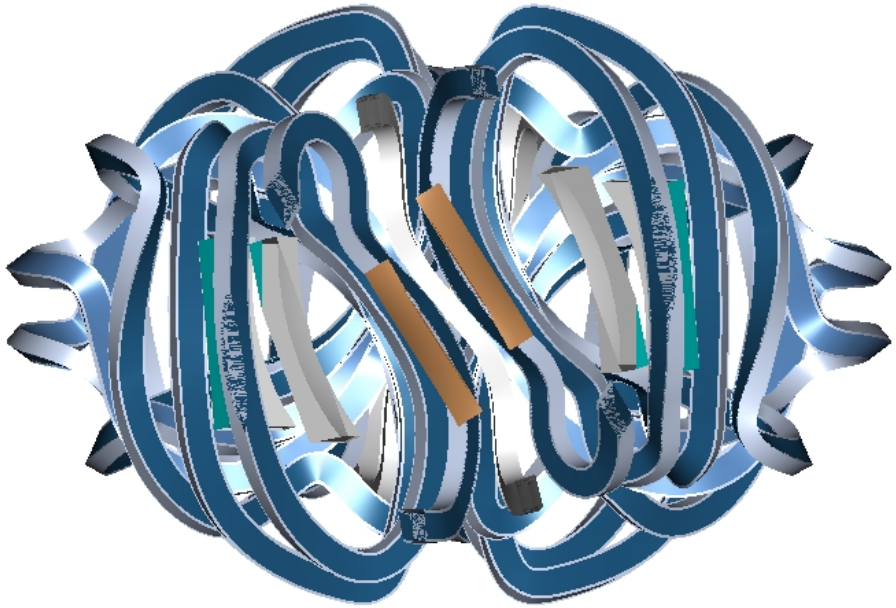
Mode Conversion, Minority heating



Upper and lower single strap antennas



High Field Side Antenna (LHD/CHS Style)

Mode conversion heating of electrons and ions on CHS

NIFS/ORNL collaboration

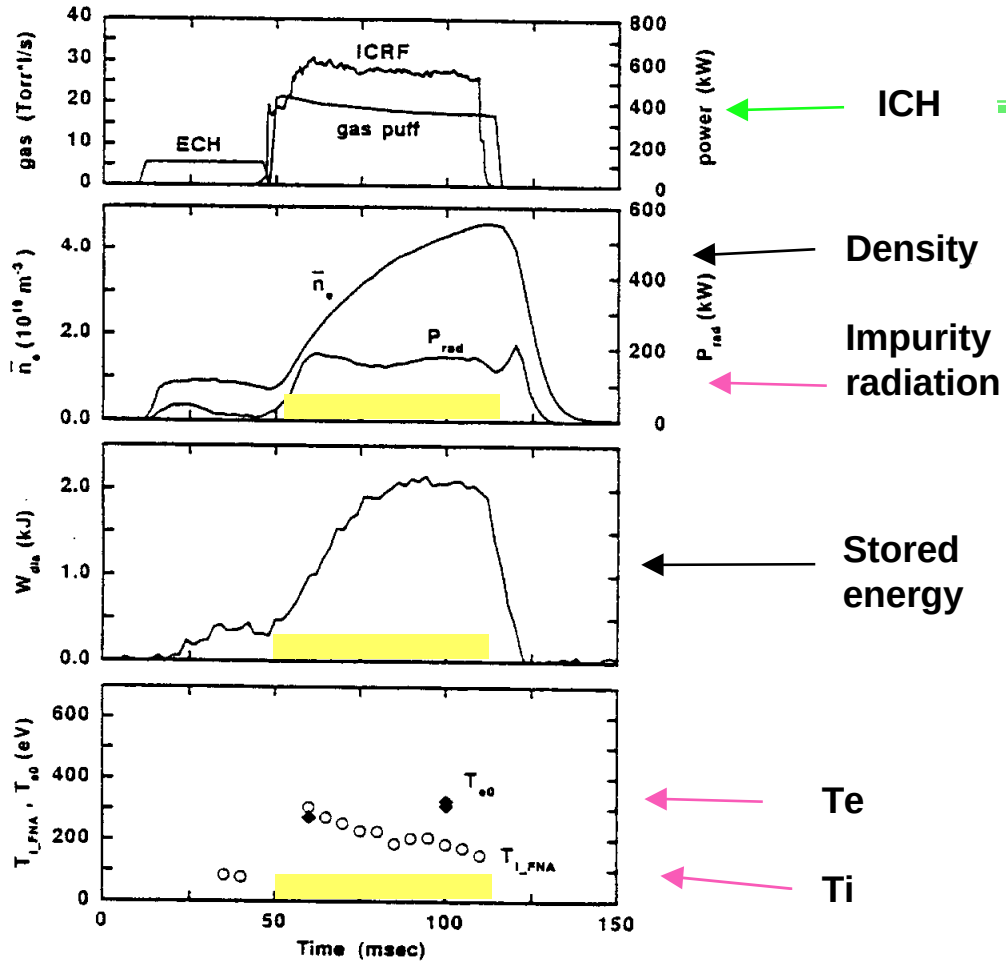
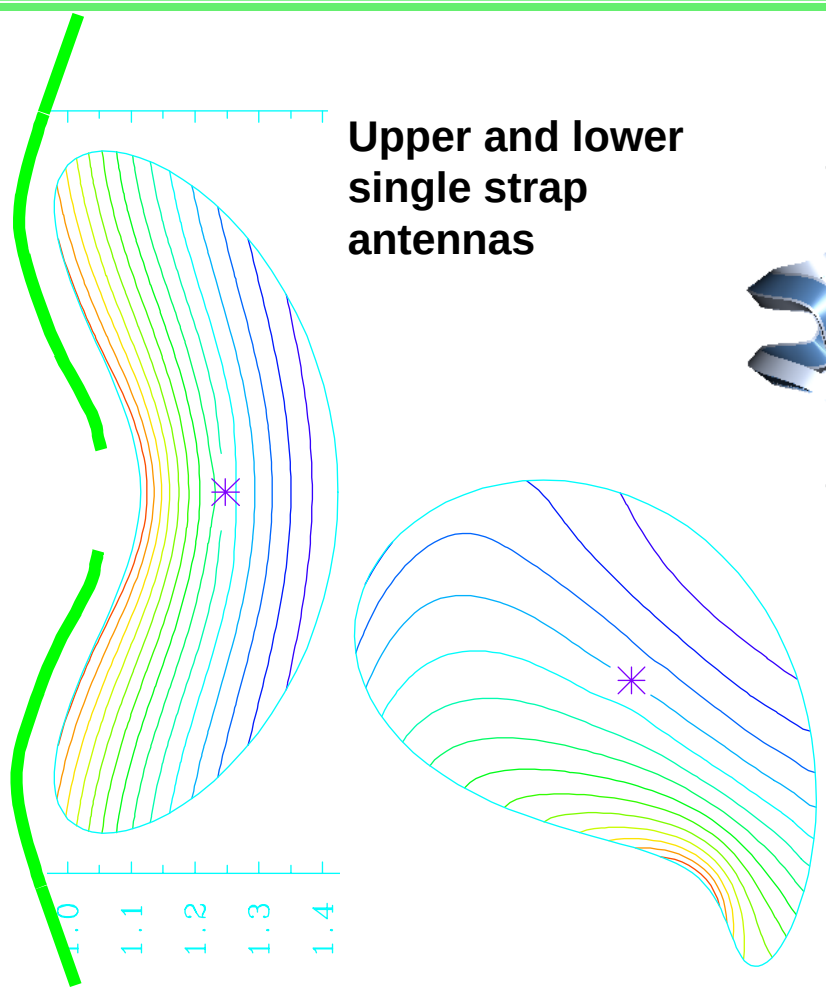


Fig. 3 Temporal evolution of plasma parameters for an ICRF heating experiment (#40991). Top column : gas puffing rate and input power. Second column : line averaged electron density and radiation loss. Third column : stored energy measured by a diamagnetic loop. Bottom column : electron and ion temperature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

Beach heating - similar to W7-AS



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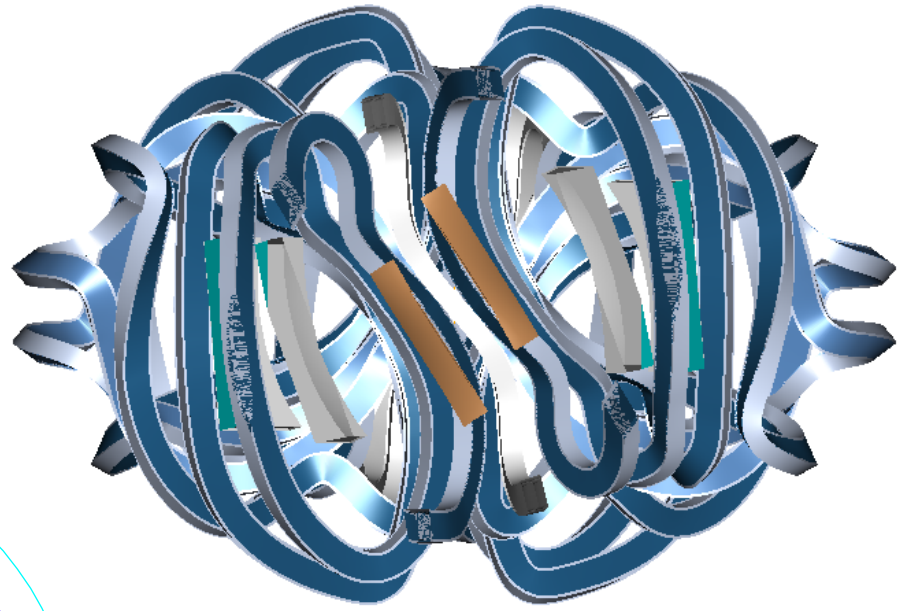
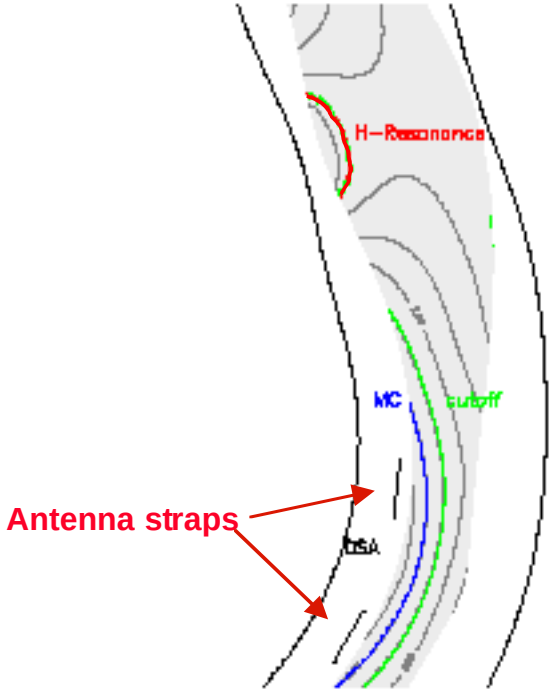


ICRF propagates to lower field “beach” region

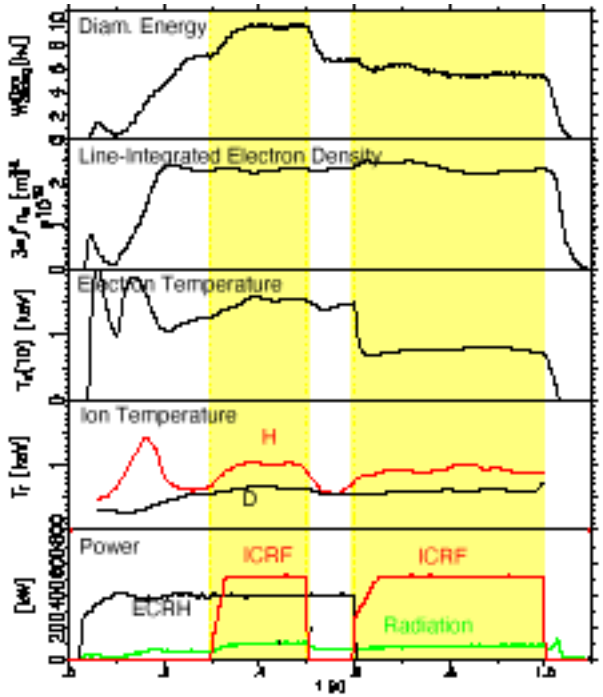
High Field Side Antenna (LHD/CHS or W7-AS Style)

Magnetic Beach heating on W7-AS

Similar to Model-C, mirror machines



Magnetic field lines for W7-AS showing MC resonance, cutoff layer and H-resonance

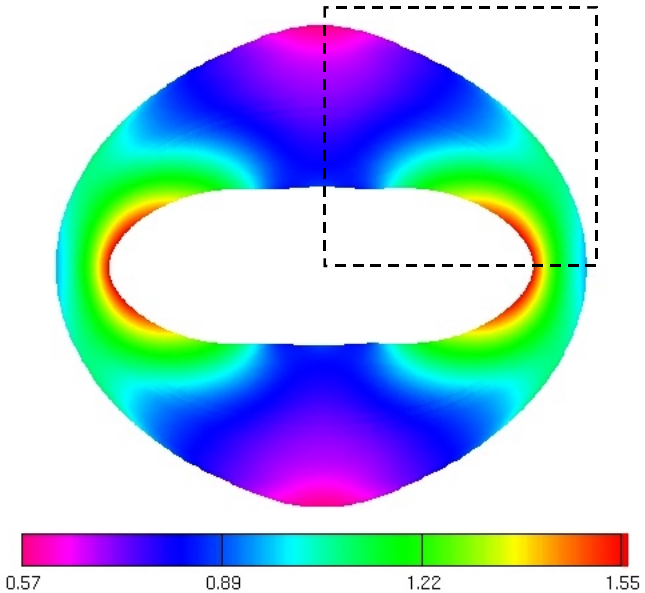


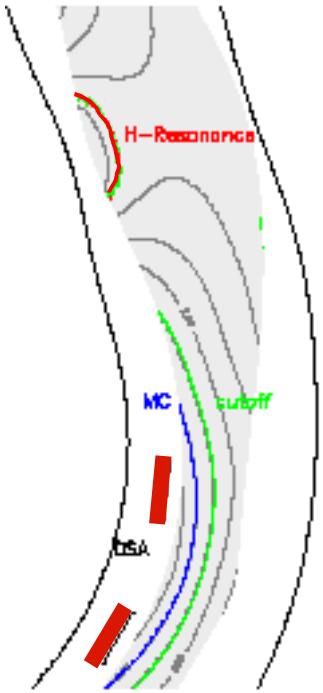
Example shot for magnetic beach heating

Hartmann, et al (1999)

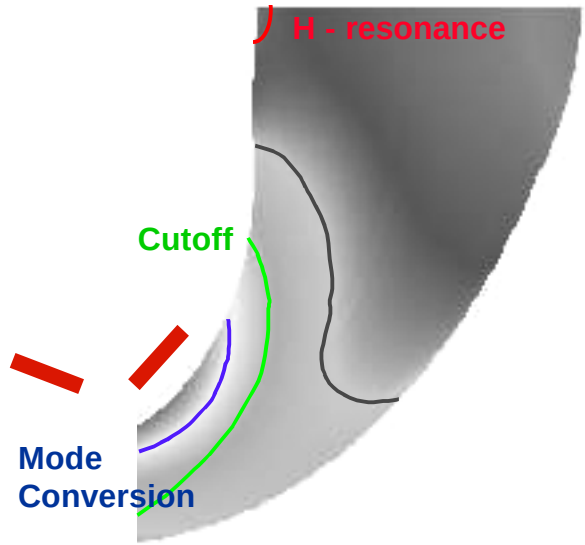
R. W. Palladino, T. H. Stix (1958)

Mod-B Contours QPS midplane



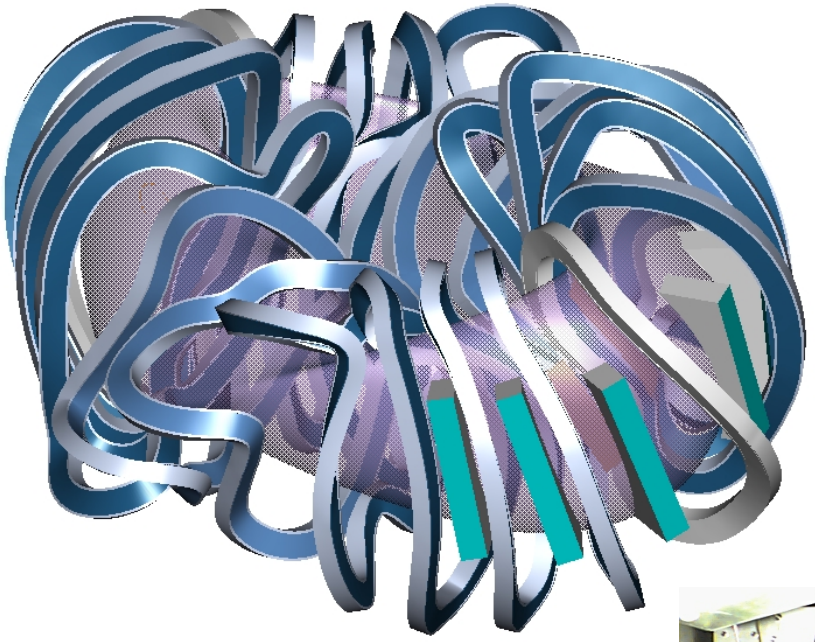


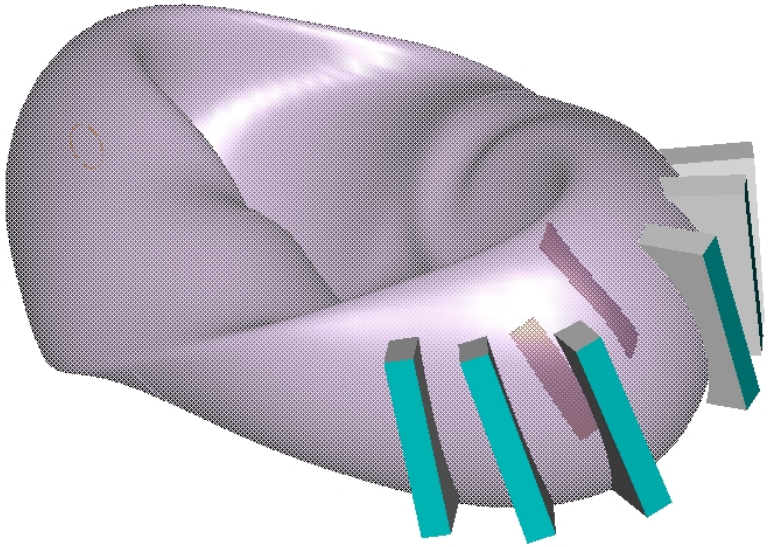
W7-AS

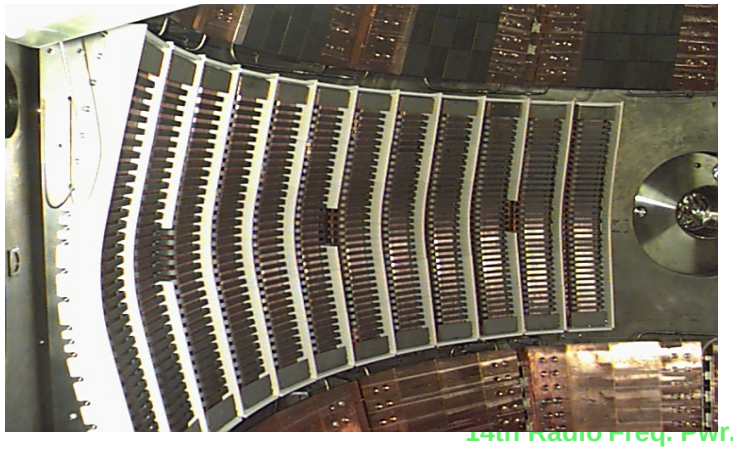


QPS

FW and HHFW array for current drive and flow control (NSTX style)







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ICRF and ECH/EBW summary

- QAS & QOS offer exciting opportunities in ICRF, ECH/EBW
- ECH will be a mainstay, EBW is a good high beta option
- ICRF is successful on similar sized stellarators
- Access and conditions for ICRF look favorable
  - Several possible ICRF antenna designs
    - Low field side antennas similar to NSTX
    - High field side antennas may be possible similar to LHD/CHS, W7-AS
  - HHFW, Mode conversion & magnetic beach heating also feasible
- Questions to ponder as we go forward
  - ICRF antenna - Outside, inside or both?
  - FWCD antenna size and directivity?
  - EBW emission/heating optimization?
  - LH frequency and port size?