Topics for LAB

- RF details/amplification (PVR).
- Review the OH analysis (PVR).
- Discuss measurements/issues for:
  - flows,
  - bootstrap currents,
  - transport.

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FUSION ENERGY DIVISION

ECH, EBW and ICRF for QPS

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D. B. Batchelor, M. D. Carter, ORNL
G. Taylor PPPL

April 24, 2001

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

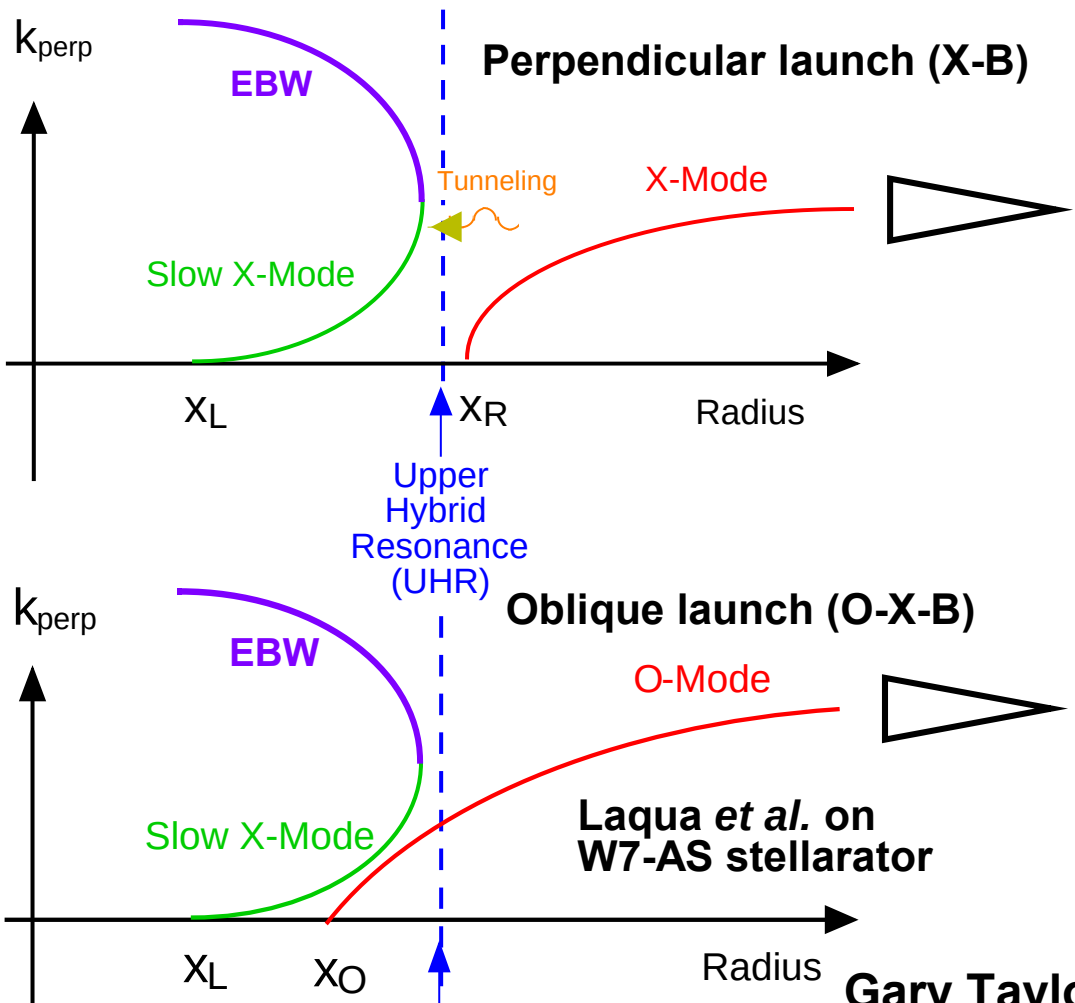
- Heat ions and electrons at high density
  - Mode conversion into an ECH target or ICRF only
  - High field, inside antenna
- Heat bulk ions at high density
  - Beach heating, ECH an target or ICRF only
  - High field, inside antenna
- Heat electrons at high density/beta - EBW

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

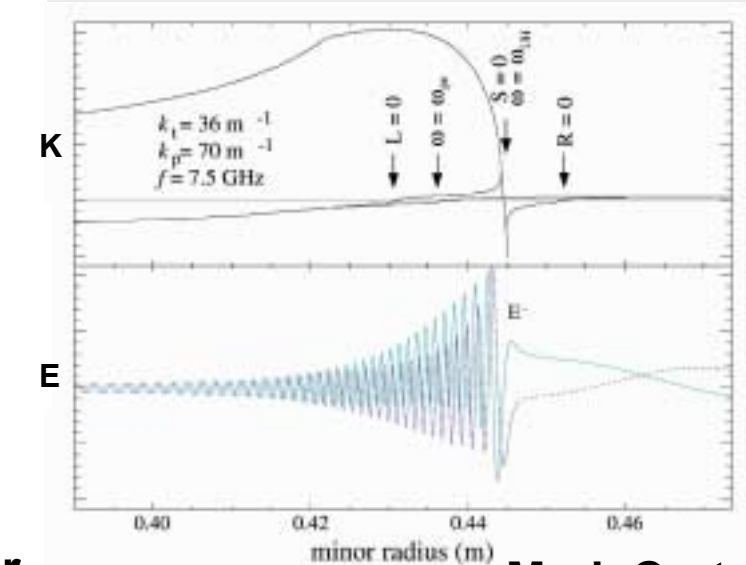
Mode Conversion to EBW at the Upper Hybrid Resonance



Gary Taylor

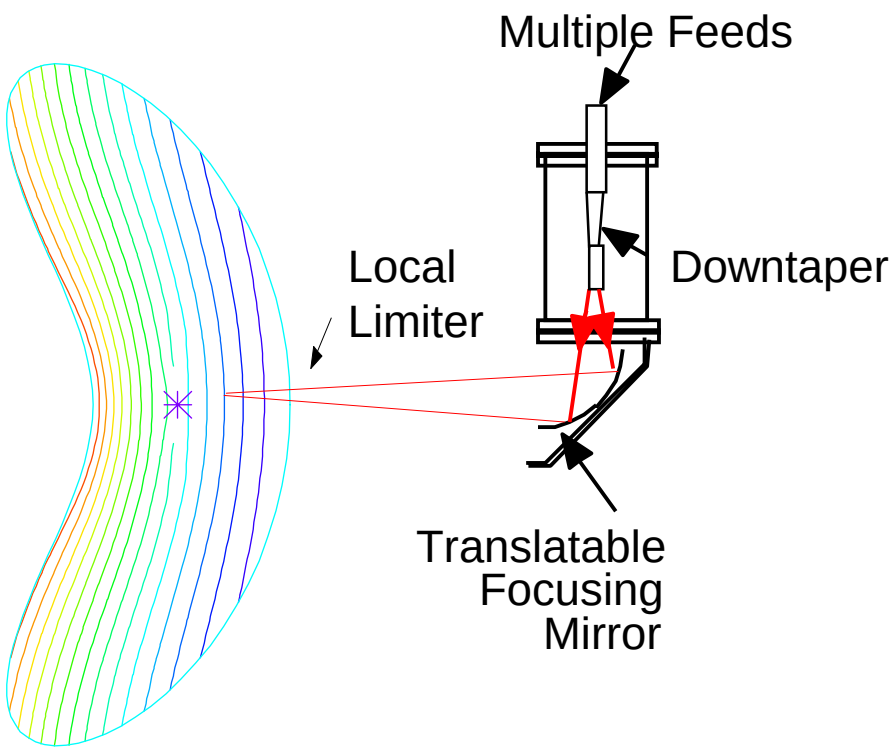
With a locally steepened density profile at the Upper Hybrid Resonance, the X-mode can tunnel through to the EBW mode

Heating is the reciprocal of the emission (MST, CDX-U, NSTX)



Mark Carter

Conceptual layout of 28 GHz $n_{//} = 0$ Launch EBW antenna located on QPS midplane

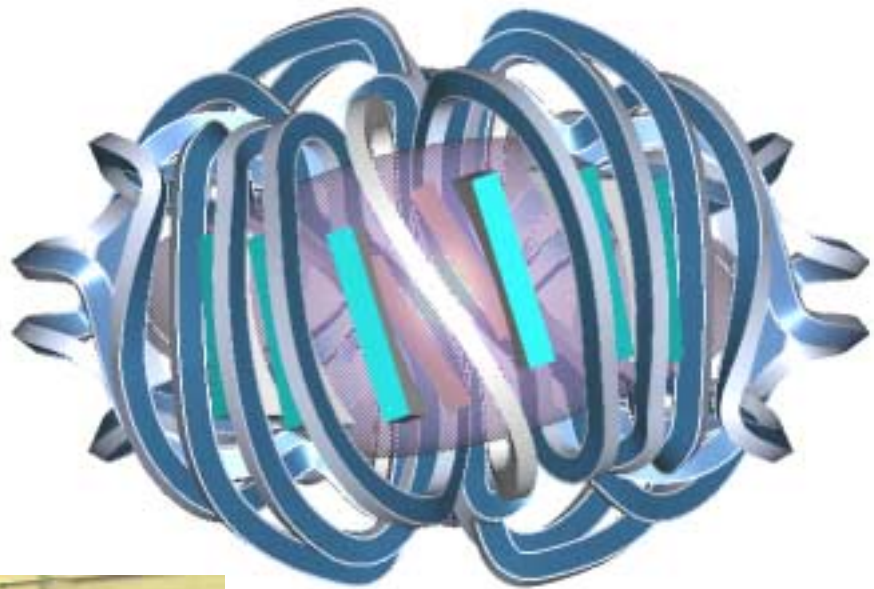


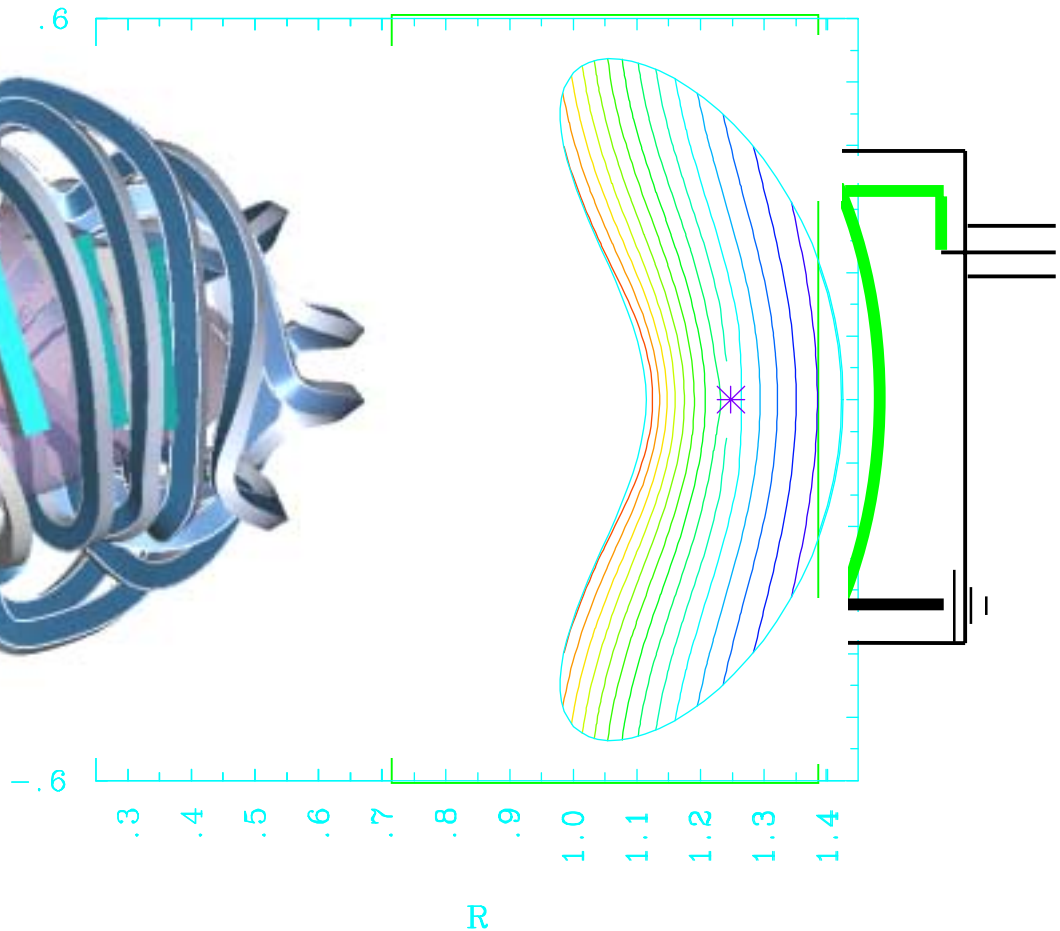
- **Focusing mirror translated poloidally to vary $n_{//}$ at EBW resonance location**
- **Local limiter to control the scrape off density profile for maximum X-EBW mode conversion**

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)

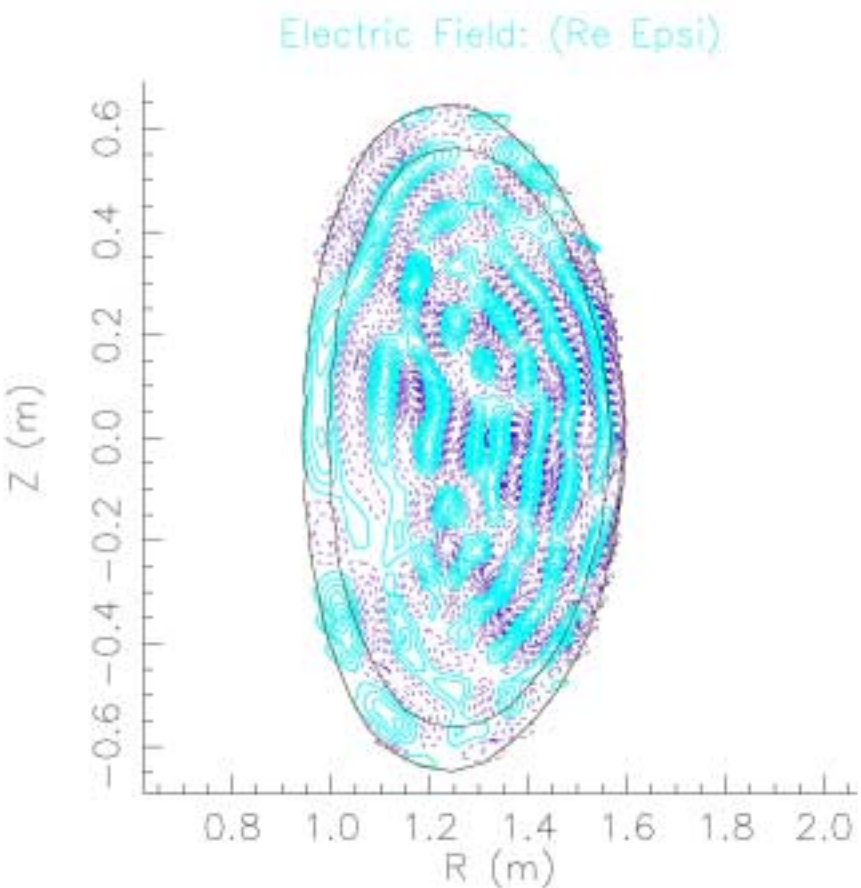
FW & High Harmonic FW and Minority heating

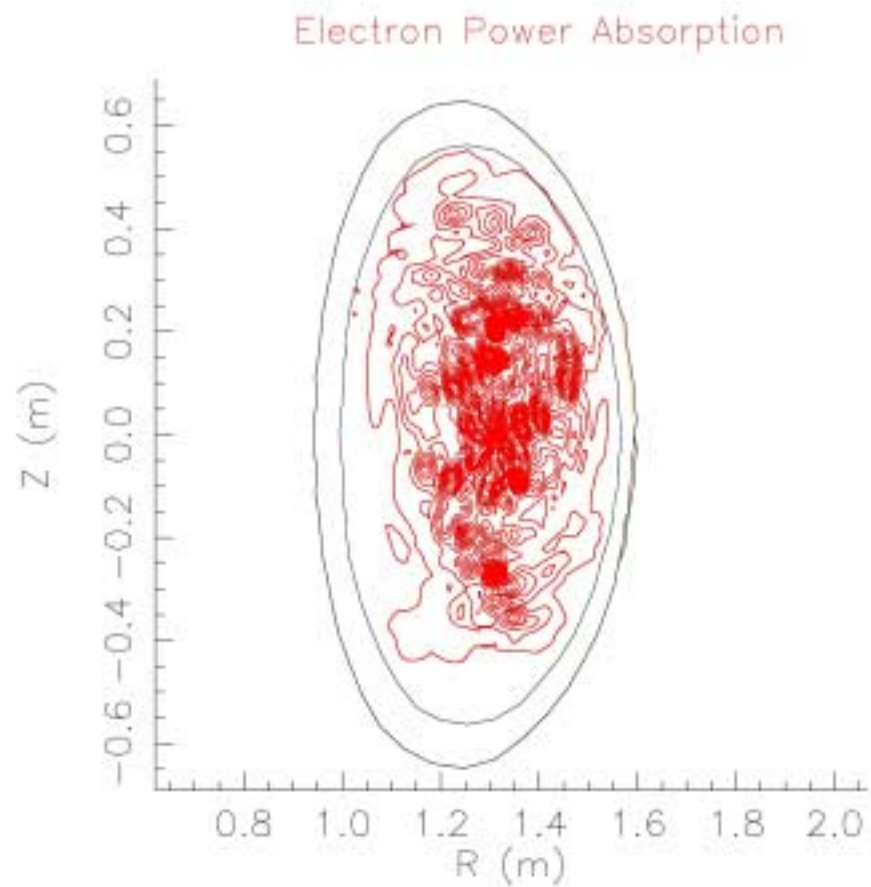




Low Field Side Antenna (NSTX style)

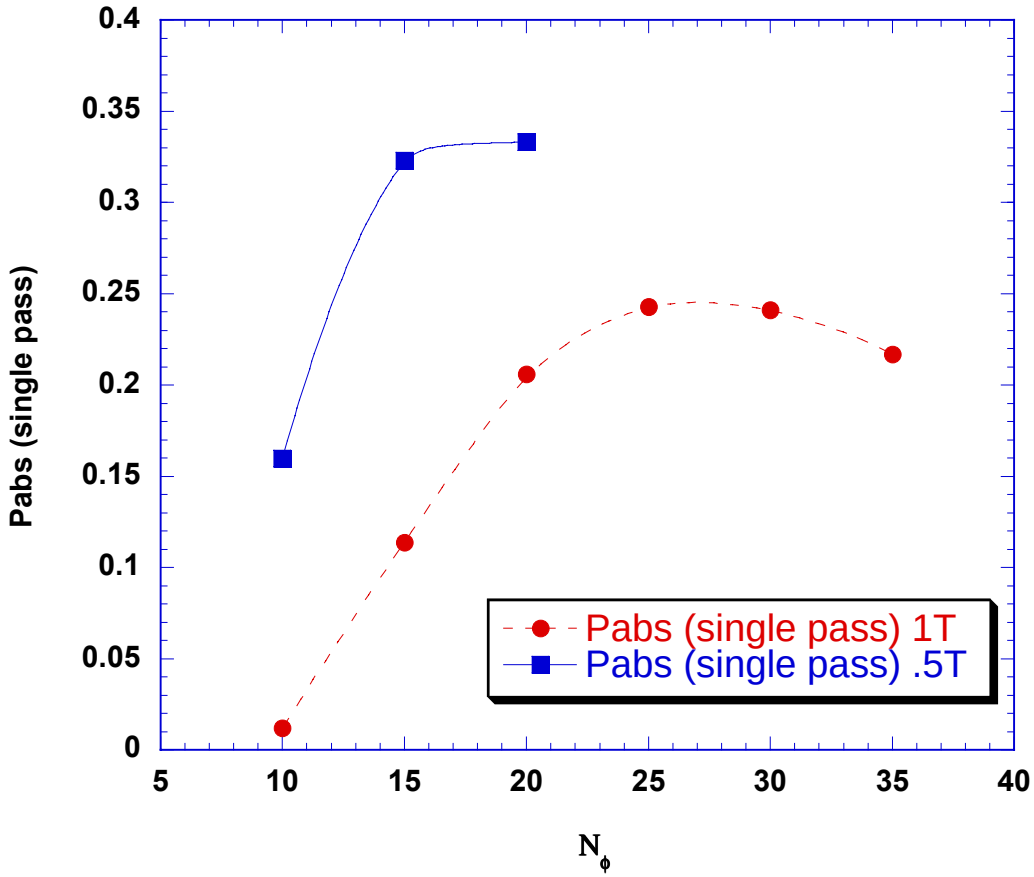
High Harmonic FW Absorption 1T 1% beta 60 MHz





Fred Jaeger

Single pass absorption calculations for HHFW look promising

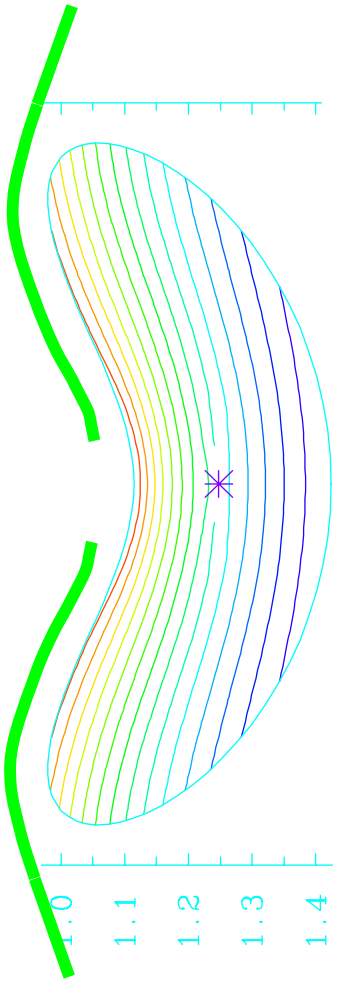


ECH Target Plasma

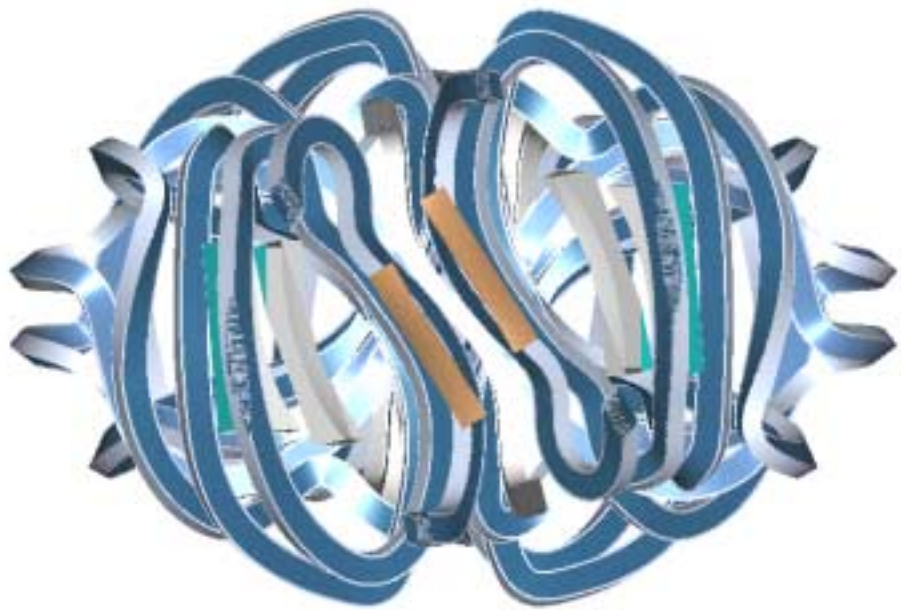
ECH power perpendicular electron heating	28 GHz 4 @ 300KW ea. 2nd 28	53 & 56 GHz 4 @ 200KW ea. 2nd 53
Parameter	**low**	**high**
B (T)	0.5	1.0
R (m)	0.83	0.83
a (m)	0.35	0.35
V_p (m^3)	1.78	1.78
P (MW)	1.0	0.5
n (10^{19} m^{-3})	0.45	1.8
$\langle\beta\rangle$ (%)	1.5	1.02
τ_E (ms)	2.25	12.1
T_{e0} (keV)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

Fred Jaeger

Mode Conversion, Minority heating

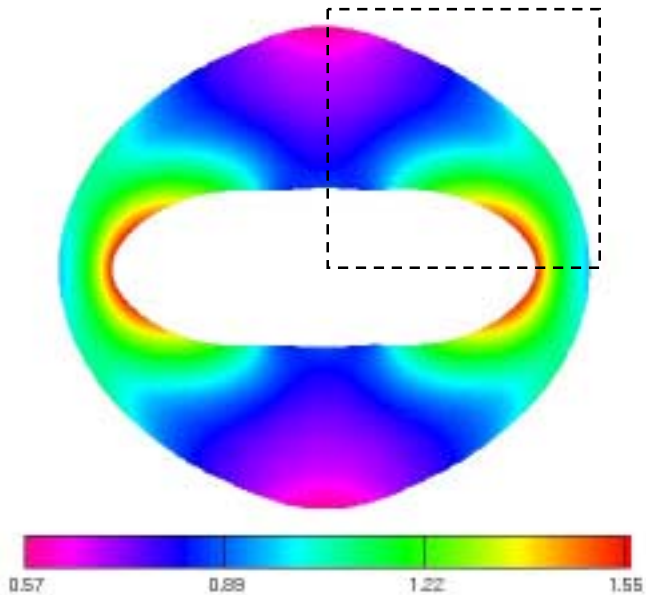


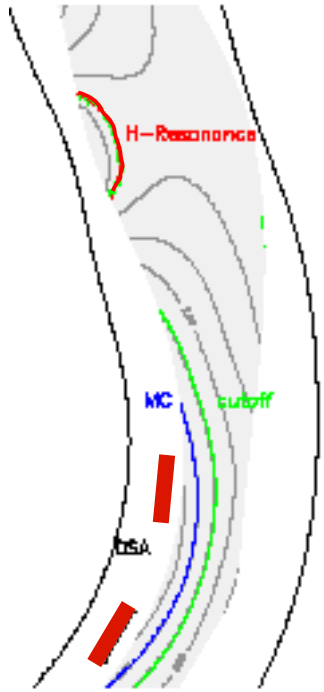
Upper and lower single strap antennas



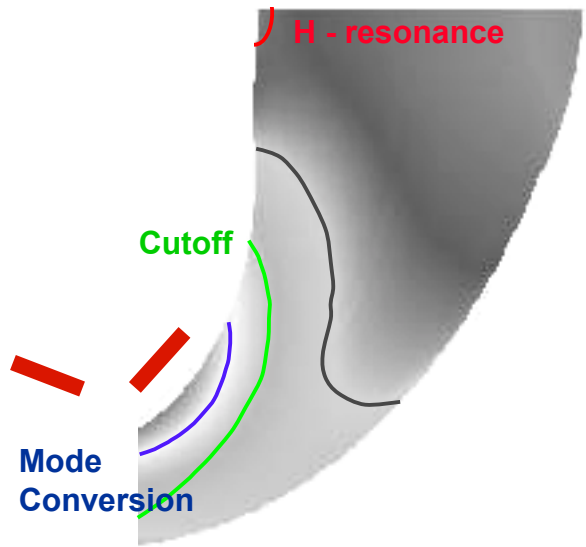
High Field Side Antenna (LHD/CHS Style)

Mod-B Contours QPS midplane



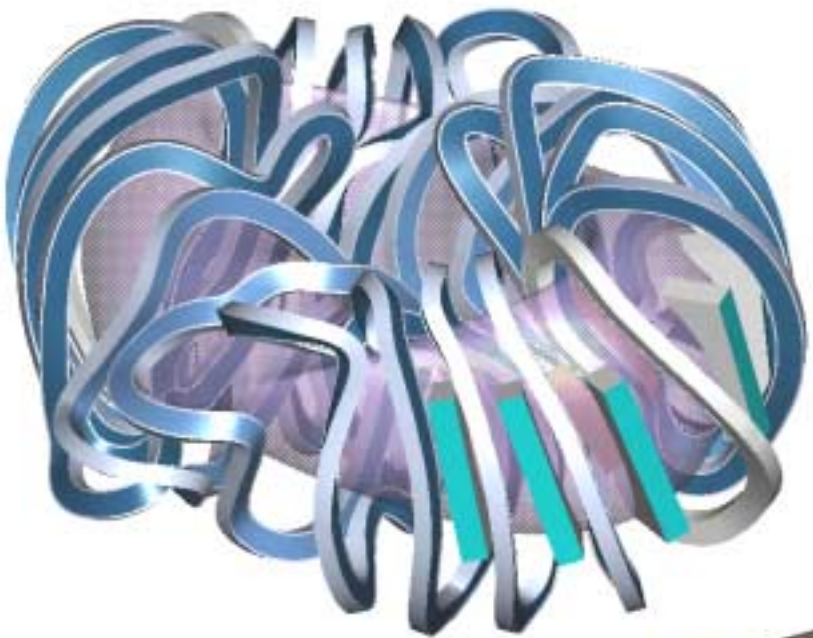


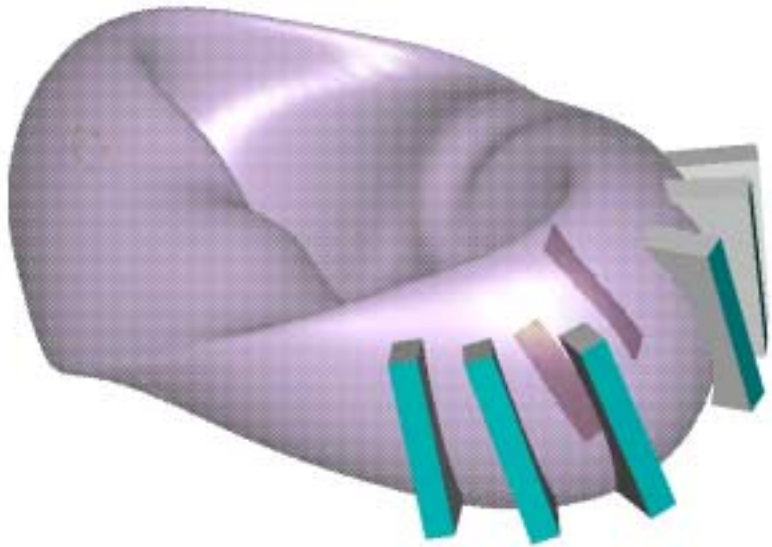
W7-AS

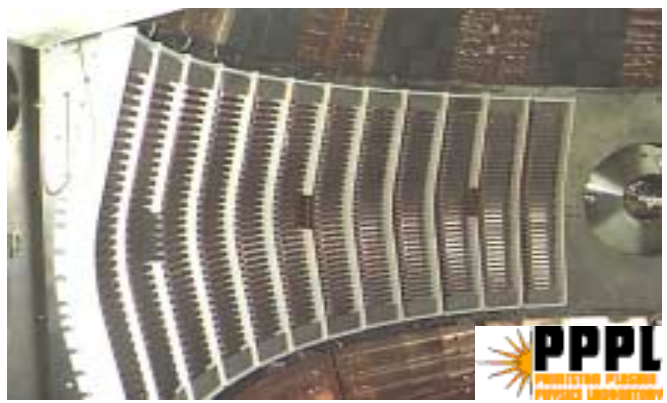


QPS

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







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?

QPS Coil Design

Presented by Lee A. Berry
for Dennis Strickler
with contributions from the
Compact Stellarator Coil Group

QPS Physics Validation Review

April 24-25, 2001

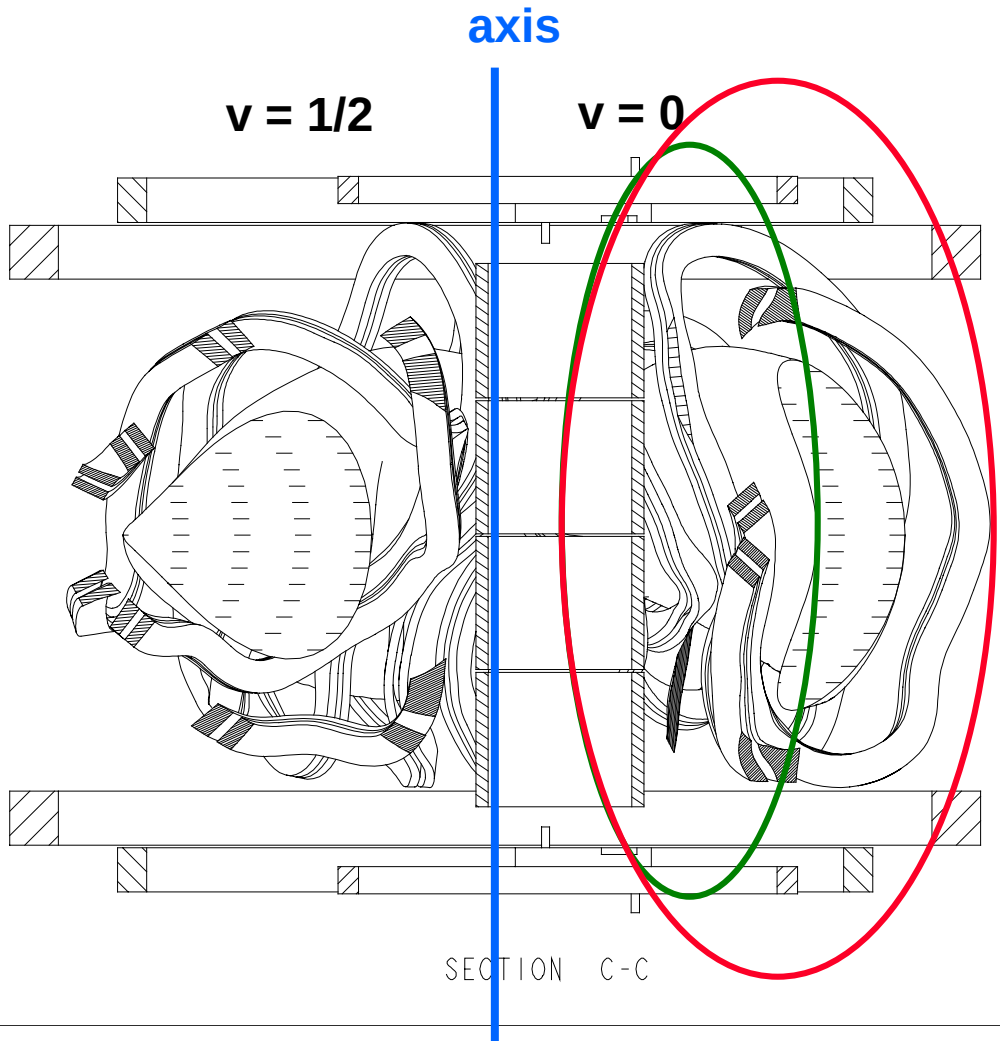
OH FLUX REQUIREMENTS ARE DRIVEN BY *LI* AND *Vt*

- **INDUCTANCE**
  - **internal: with uniform current, l_i = 0.32**
  - **external: (Hirshman and Neilson) l_{ext} = 0.72**
  - **total: 1.03 μH => (L ≈ 1-1.5 μH)* 50-75 kA => *LI* ≈ 0.1 Vs.**
- **RESISTANCE**
  - **R_p ≈ 1- 10 μΩ => 0.1-1.0 V for 100 kA and *t* = 0.1 to 1.0 s for 0.1 Vs.**

A flux capability of 0.2 Vs is adequate.

- **A 2-m high central solenoid with a race-track cross-section and a two-way flux swing of 0.3 Vs is specified for the PVR.**

THE FULL PF SET IS NEEDED TO CANCEL THE FLUX FROM THE SOLENOID THAT DOES NOT LINK THE PLASMA



- **Errors from a similar 4-m solenoid are ≈ 0.5%.**
- **Small currents, ≤ 10 kA (5% of the nominal equilibrium currents) in the inner-VF and mid-VF coils reduced the errors to ≈ 0.05%.**
- **This suggests that there is sufficient flexibility in the PF coil set to keep OH error at acceptable levels.**

Measurements to Understand Boostrap Physics in QPS

- Direct poloidal field measurements, while useful, are not a simple answer:
  - at ~50 kA, bootstrap/other currents contribute ~ 1/4 to 1/3 of the transform—very high precision measurements would be needed.
  - separation of currents into components would still not be easy even with sufficient precision.
- Magnetic measurements/reconstruction with parameter variations will, I believe provide useful understanding.

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Flow Measurements/Transport Barriers

- Doppler spectroscopy can be used for flow measurements:
  - existing sources can be augmented with laser-blowoff;
  - while not possible for all plasma conditions, this is an appropriate diagnostic for the initial (four-year) program;
  - DNB techniques for out years are possible.
- A comparison between the enhanced confinement performances between various stellarators will provide qualitative information on role of perpendicular vs parallel viscosities.

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Neoclassical Transport

- Can neoclassical transport losses be controlled at low A?
  - While models say that we have been successful, validation is needed.
  - The optimization is more difficult at low A, and compromises must be made.
    - » QPS allows bootstrap.
- ECH, configuration variations, and Te profiles provide the needed experiments.