QOS Power and Particle Control

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Outline

- Divertor versus limiter operation
- Magnetic configuration
- Power handling
- Particle control
- Impurity control
- Vacuum and plasma-wall interactions
- Summary and plans

Definition of Divertor vs. Limiter Operation

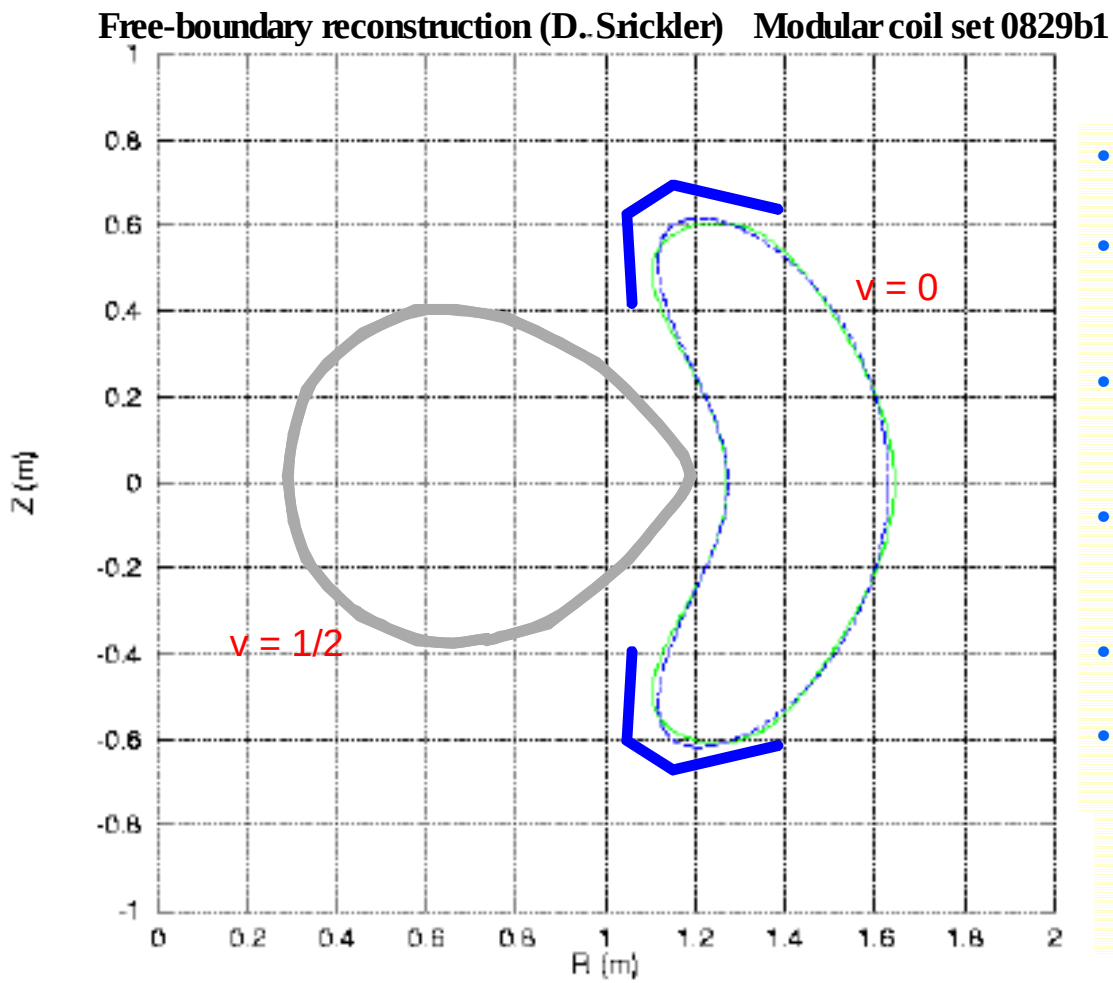
- Divertor baffles intercept open field lines
  - **This could be islands or stochastic regions outside the separatrix**
  - **Divertor baffles have some plasma as buffer between the solid surface and the main plasma**
  - **This is advantageous for neutrals re-ionization and high recycling as well as for impurity screening**
  - **For symmetric operation, one set of baffles per field period is needed**

- Limiters intercept closed field lines
  - **Connection lengths are long**
  - **No separatrix operation**
  - **Major recycling neutrals source in the main plasma**
  - **Major impurity source in the main plasma**

Magnetic Configuration in the Plasma Boundary

- Present experience on modular stellarators (Wendelstein) indicates that the most effective location for intercepting power and particles are the top and bottom of the bean-shaped cross-sections at v=0.
- First results on field-line tracing outside the LCMS on QOS show that the connection lengths within a couple of cm outside the LCMS are long (several toroidal revolutions) (=> R. Fowler, J. Lyon).
- This looks favorable for effective power and particle control outside the LCMS, i.e. in divertor configuration.
- To determine where power and particles leave the confined plasma, i.e. as guidance for the design of the plasma-facing components, we will
  - **Generate field-line plots outside the LCMS for the top, inside and outside the cross-sections at the start and halfway through the field - period.**
  - **Generate plots of the interception of energetic particles with the LCMS**

QOS Divertor Baffles

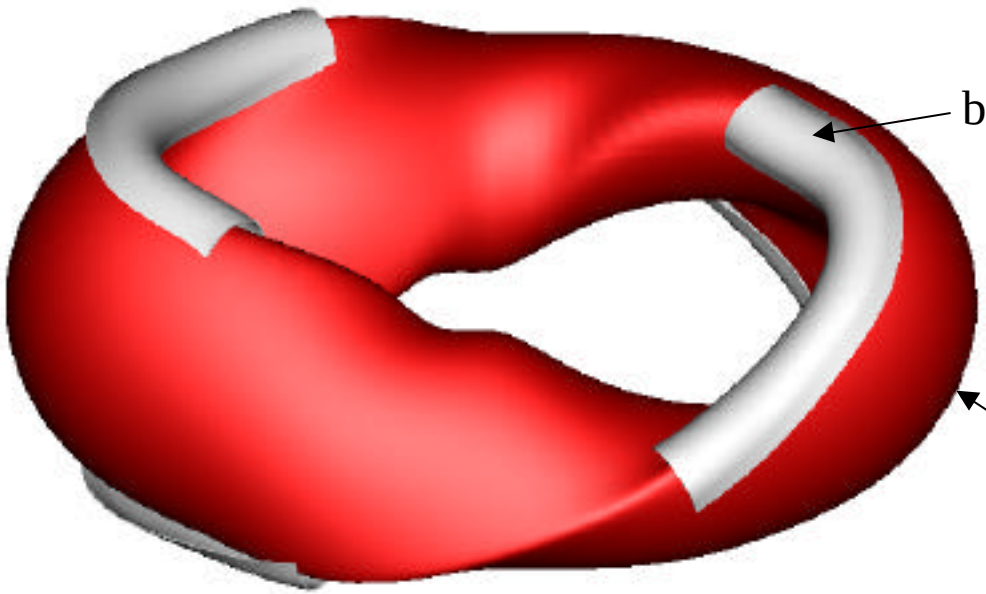


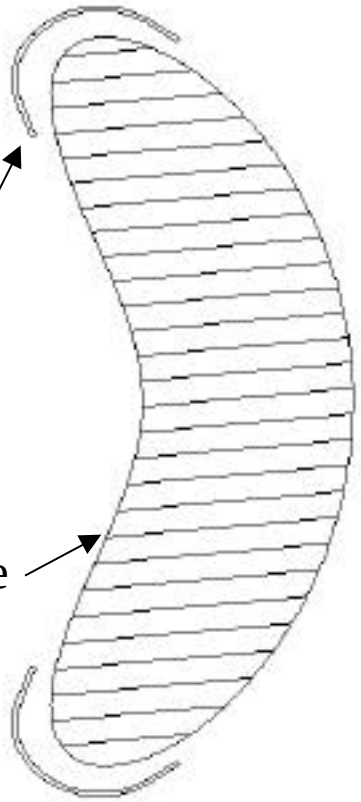
- divertor baffle toroidally discontinuous
- for a total of one toroidal revolution, total length ~ 6 m
- for this case the baffle surface facing the plasma ~ 3.6 m2
- 80% of the power intercepted by baffles: 1.12 MW
- average power density: 0.3 MW/m2
- peaking factor 3: maximum power density: ~ 1 MW/m2

3-D View of the Divertor Baffle

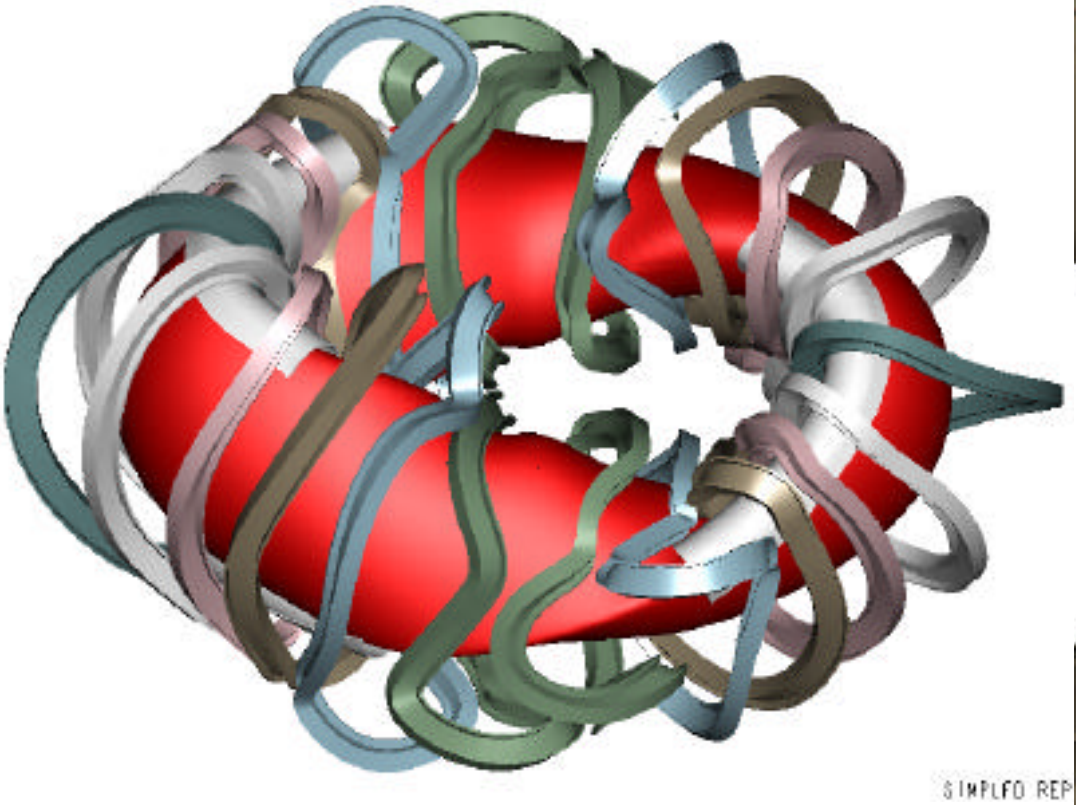
B. Nelson

- Baffles located at “tips” of plasma surface
- Baffles symmetric with field period geometry



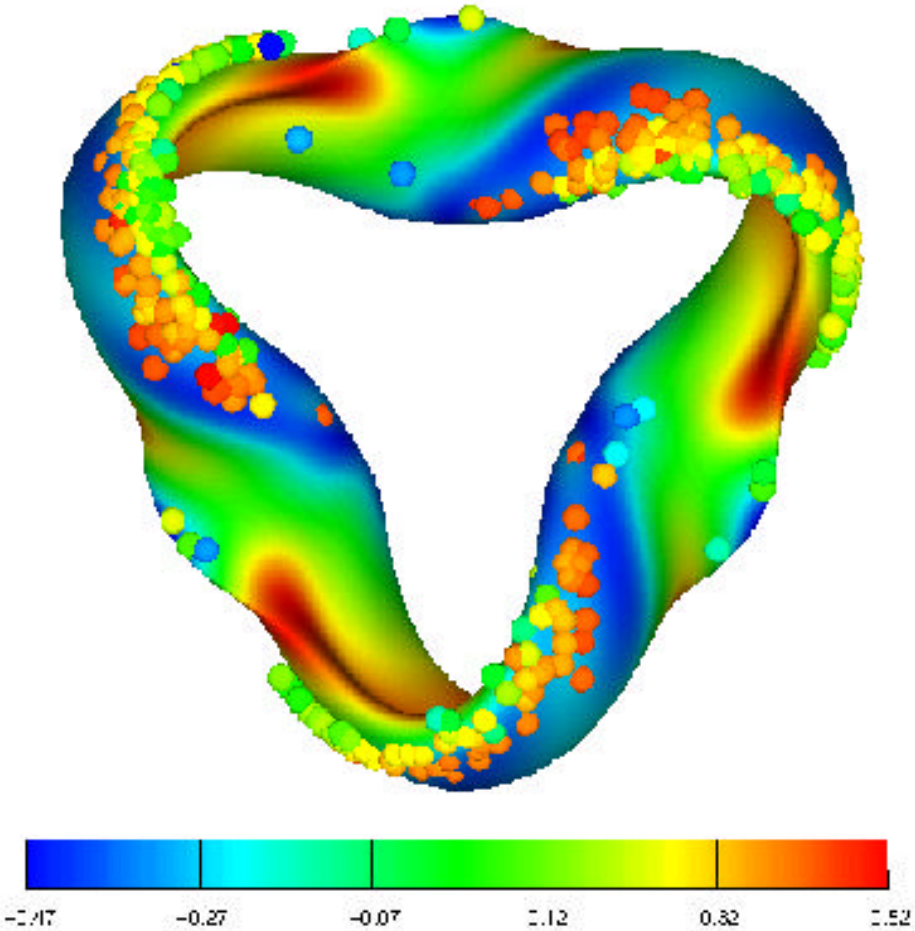


Baffles Fit Within Modular Coil Structure

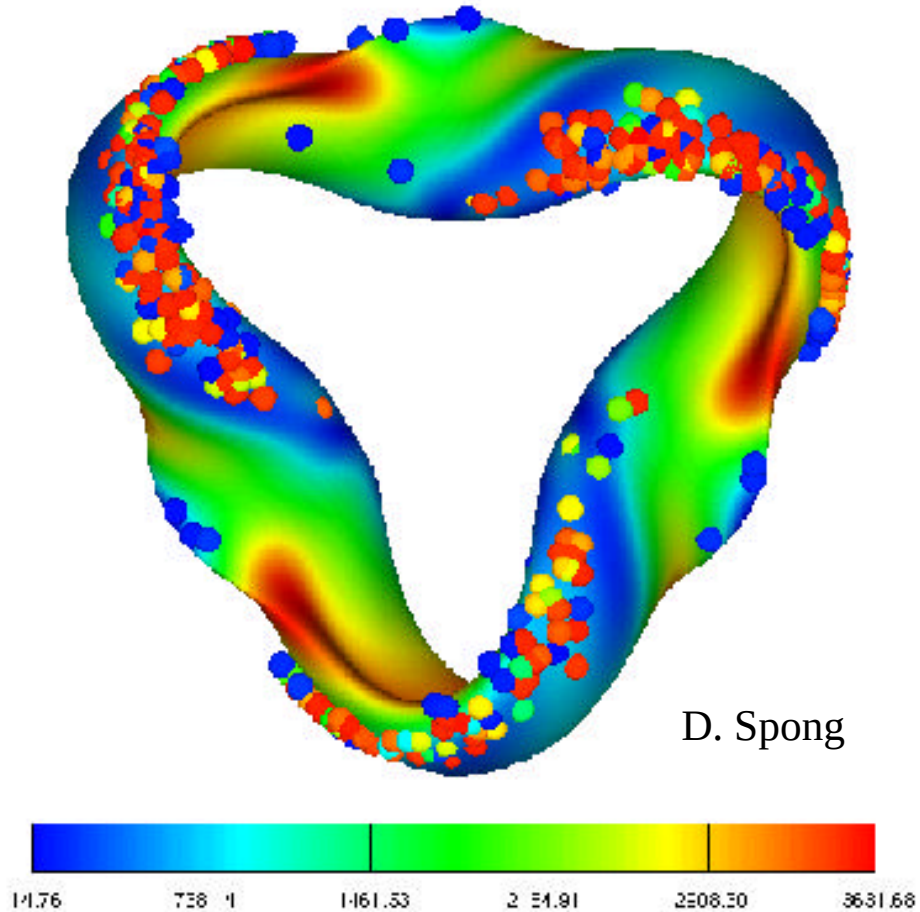


Alpha particles predominantly exit the plasma in the low field regions:

(legends show particle color coding: left $v_{||}/v$, right energy; flux surface color contours show magnetic field strength: blue=low, red=high)



Exit value of $v_{||}/v$



Exit Energy (keV)

Power Handling

- Heating power into QOS:
  - **P_{input} = 0.4 MW ECH + 1.0 MW ICRF = 1.4 MW**
  - **Pulse duration t ≤ 1.0s**

- How does the power come out of the plasma:
  - **Conduction and convection to limiters / divertor plates**
  - **Energetic particles in loss cones**
  - **Radiation (to all walls, coils, etc.)**
  - **Charge-exchange (to all walls, coils, etc.)**

Power Handling cont'd

Design considerations for plasma-facing components for power handling:

- High power-density areas:
  - **divertor baffles: assume 80% of P_{input} @ 20 MW/m^2**
    => 1.12 MW / 20 MW/m^2 need 0.056m^2 wetted surface (peaking factor!)
  - **energetic particles: fraction and location/distribution need to be determined**
- Low power-density areas:
  - **plasma surface = 15 m^2; assume 80% radiation and CX power: average surface power density: 0.075 MW/m^2** ***(lower at winding surface!)***
    fraction to coils: 10 - 20% => ~ 0.1 - 0.2 MW at $\leq$ 0.075 MW/m^2
  - **Bell jar (cylinder walls): 80% radiation and cx : 1.12 MW / 100m^2 ~ 0.01 MW/m^2**

Neutrals Control

- We assume (and need to verify) that particles (thermal and fast) leave the plasma predominantly at the sharp ridges
- We need to find out if considerable fractions of particles and power come out at the outer midplane
- Neutrals are confined mechanically by baffles and have a large probability of re-ionization by the boundary plasma
- Mechanical baffling and local recycling can lead to high-recycling divertor operation with low electron temparatures
- This will minimize the build-up of neutral pressure in the vessel
- Additional neutrals control will be achieved by surface pumping
  - **Boronization**
  - **Large area titanium getter pumping**

Density Control Strategy

- The bell jar volume of ~50m^3 provides a large reservoir for neutral gas which can have a major effect on efficient density control

- We are developing multiple strategies for density control:

  1. **Control of the neutrals sources through mechanical confinement with divertor baffles and re-ionization of neutral particles**
  2. **Recycling control through surface pumping via boronization of all plasma-facing components**
  3. **Large-area titanium pumping of neutral gas: s=20,000 L/s per m^2 for molecular gas; ~10 - 20 m^2 possible**
  4. **Direct fueling of the core plasma with gas injectors at the divertor baffles and/or pellet injection**

Estimate of Neutral Gas Density

$$n = \frac{\frac{N/\tau_p}{1-R} \cdot \frac{\lambda_{gas}}{\bar{v}_{gas}}}{V_{belljar}}$$

parameter	DIII-D	QOS
N	1.2×10^{21}	1.2×10^{20}
τ_p [s]	.2	0.02
N / τ_p [s]	6×10^{21}	6×10^{21}
R	0.9	0.5
λ_{gas} [m]	0.1	10
v_{gas} [m]	1.2×10^{3}	1.2×10^{3}
V_{edge} [m^3]	7	50
n [m^{-3}]	7.1×10^{17} (2×10^{-5} Torr)	2×10^{18} (6×10^{-5} Torr)
$\frac{n \cdot V_{edge}}{N}$	$\frac{4.9 \times 10^{18}}{1.2 \times 10^{21}} = 0.004$	$\frac{1 \times 10^{20}}{1.3 \times 10^{20}} = 0.7$

Impurity Control

- Plasma-surface interactions
  - **Most intense impurity source will be where power and particle fluxes intercept solid surfaces close to the plasma, i.e. at the baffles**
  - **Boundary plasma between baffle surface and LCMS will help shield main plasma from impurity source**
  - **S.S. coil casings may have to be protected with graphite from cx bombardment**
- Leaks in stainless steel coil casings
  - **Large number of coils inside the vacuum…large potential for leaks/virtual leaks…need first rate Q.A. during fabrication**
  - **Gas cooling will make leaks more benign and will help to diagnose leaks**
- Thick aluminum-oxide layers on bell-jar walls
  - **Hard to remove with discharge cleaning**
  - **Distance to the plasma helps**

Vacuum Conditions and Plasma-Wall Interaction Issues

- Double vacuum seals with viton o-rings (diff. pumping) should provide sufficiently low base pressures (~10^{-8} Torr) and leak rates (~10^{-5} TorrL/s)
- Outgassing of Al can be as favorable as s.s. ... baking temperatures of 150 ^{o}C for Al and 300 ^{o}C for the graphite surfaces should be adequate
- Wall conditioning should include glow-discharge cleaning and boronization
- Glow discharges and other plasma-surface interactions will cause mixed materials surfaces: Al, graphite, s.s., (Ti)
- Titanium migration from the pumps to PFCs needs to be avoided; boronization will help covering up Ti contamination
- To minimize chemical sputtering, bulk-boronized graphite should be used for the divertor baffles
- The heavy oxide layers on the Al bell jar could be an inexhaustible oxygen source… covering the Al surface with boronization should help

Summary and Plans

- The boundary conditions, as we know them so far, look favorable for divertor operation in QOS:
  - **First results of the magnetic field line modelling outside the LCMS indicate long connection lengths in the plasma boundary**
  - **Experience on Wendelstein shows preferential power and particle outflow in the top and bottom of the bean-shaped cross sections**
- Future plans include:
  - **Detailed field line mapping of the plasma boundary**
  - **Neutrals modeling of the baffle region**
  - **Mapping of energetic particle outflow**
  - **Modeling of power and particle fluxes on divertor baffles**
- Many issues of power and particle handling are similar between QOS and NCSX and can be addressed in similar ways for both devices