# Summary of Boundary Physics Issues and Modeling Results for FIRE

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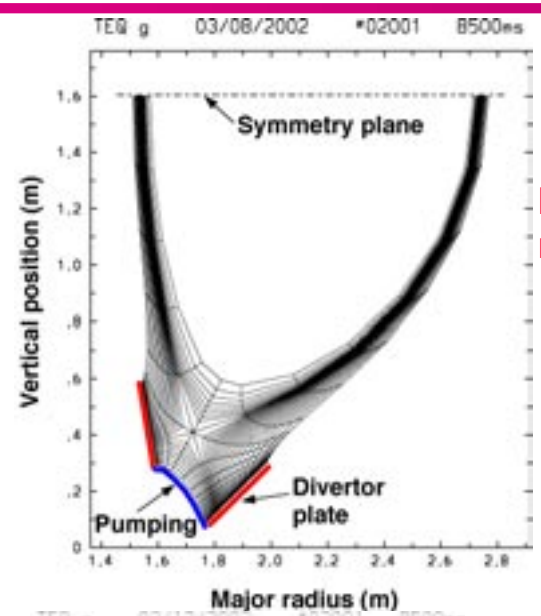
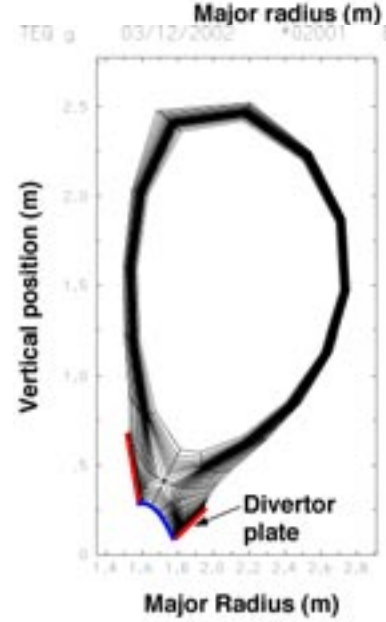
# FIRE is designed for a double-null divertor

- FIRE divertor must tolerate 28 MW into the SOL
- For 150 MW fusion power, helium must be removed at a rate of $5 \times 10^{19}$ particles/sec
- Edge density is set to $3 \times 10^{20}$ $m^{-3}$
- Unity recycling with PF pumping

- Transport simulations with 2D UEDGE
- Solve for $n_i$, $u_{||i}$, $T_e$, $T_i$, $n_g$, & $u_{||g}$
- Classical parallel transport, anomalous perpendicular
- Multi-species impurities




Double null




Single null variant

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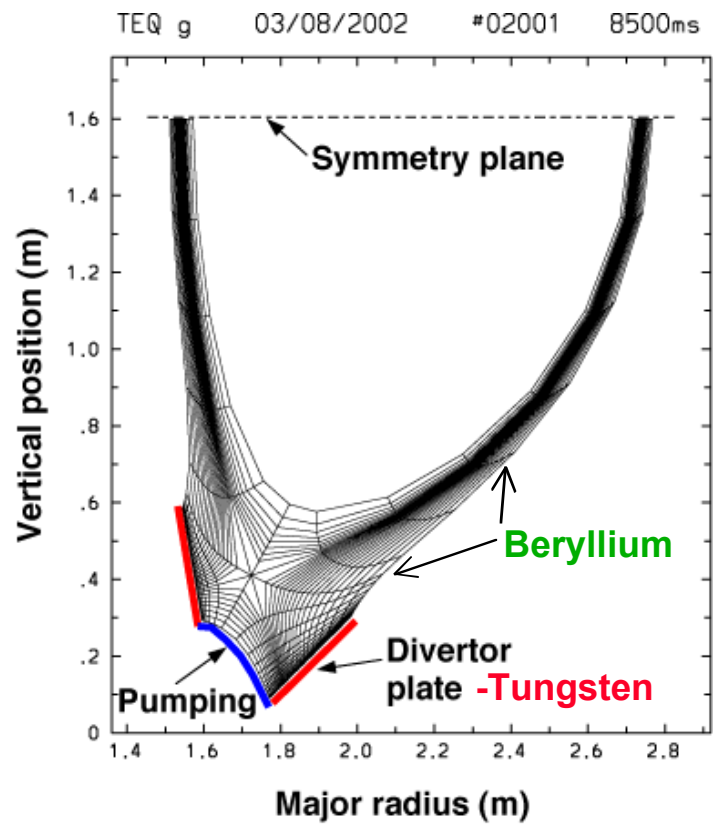
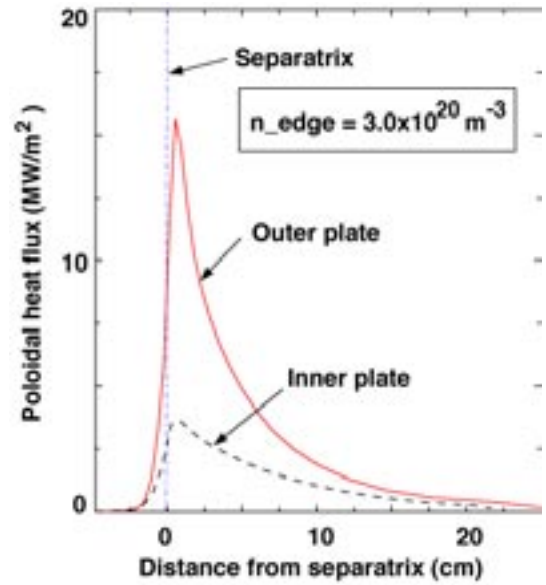
# FIRE is divertor is tungsten with beryllium walls

- FIRE divertor uses brush-tungsten divertor tested to 25 MW/m$^2$
- Pumping is provided through the private flux regions of ~5 e-kAmp
- Feed-back control of heat to upper and lower divertors used to obtain balanced power deposition; does not rely on precise magnetic balance

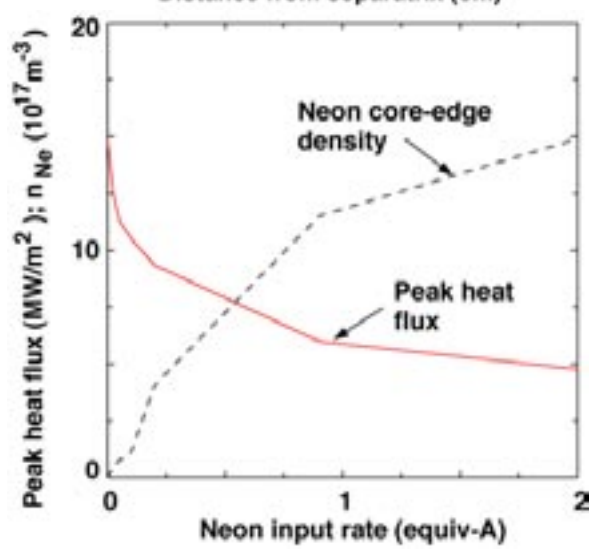


# FIRE base-case meets divertor requirements

- Peak heat-flux is 15 MW/m$^2$ ignoring impurity radiation
- PF pumping of helium keeps $He^{2+}$ core-edge density < 2.5%
- Hydrogen particle throughput of 4 e-kA is within pumping specs.
- Neon injection can induce partial divertor detachment; heat flux < 6 MW/m$^2$




Divertor heat flux profiles

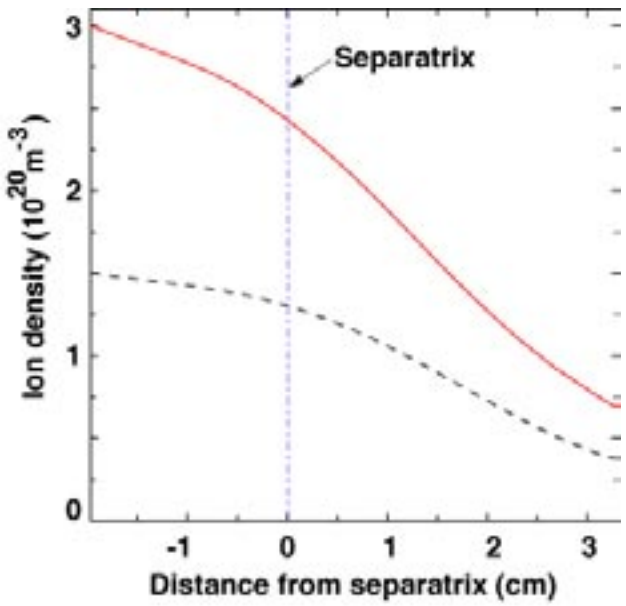



Neon injection reduces peak heat flux.

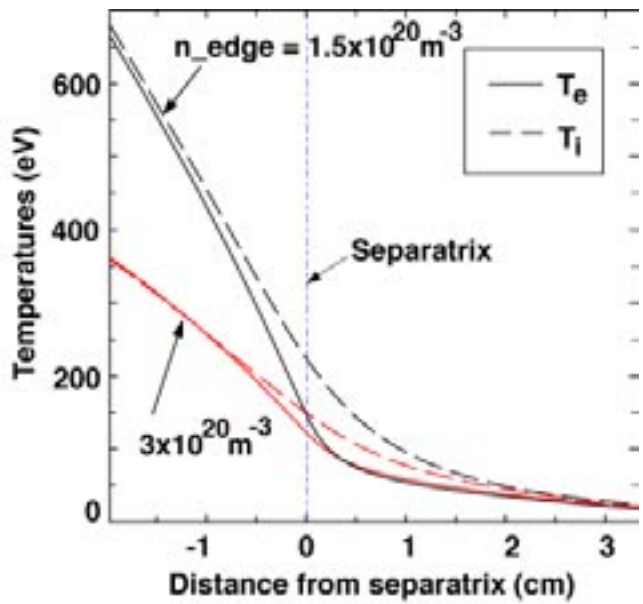
# Midplane profiles show scaling with core-edge density and transport coefficients

- **Two cases: core-edge densities of $3\times10^{20}$ m$^{-3}$ and $1.5\times10^{20}$ m$^{-3}$**
- **Anomalous diffusion is set to $D_\perp = 0.25$ and $\chi_i = \chi_e = 0.5$ m$^2$/s**

**Plasma density**

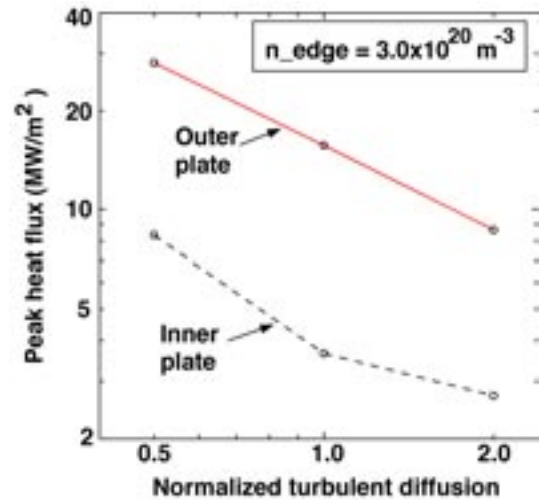



**Electron & ion temperature**



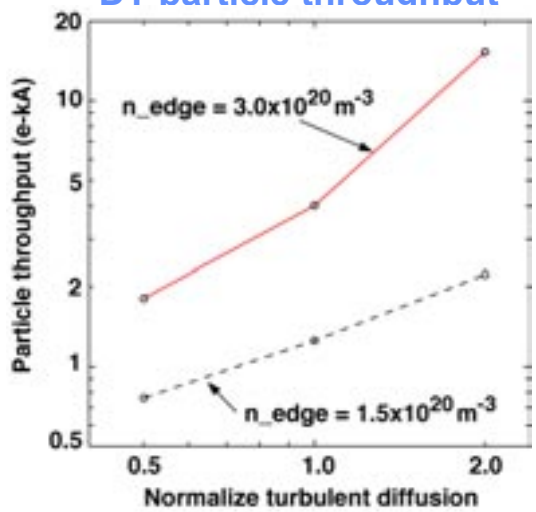
# Peak power scales nearly inversely with density and with anomalous diffusion coeff.

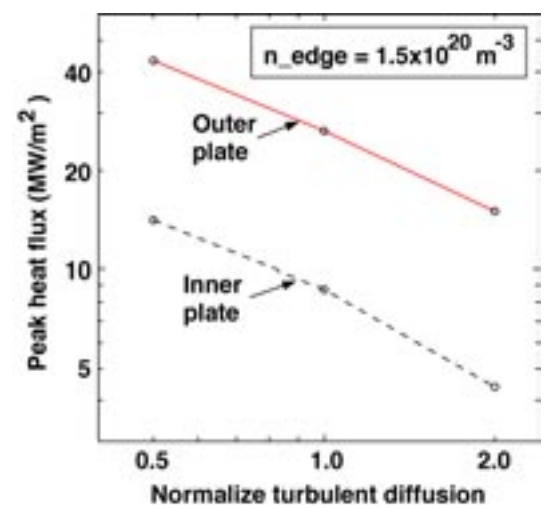
- **Diffusion is varied in the ratio $2D_\perp = \chi_i = \chi_e$ with the base-case having $\chi_e = 0.5\ m^2/s$**




Heat flux

DT particle throughput



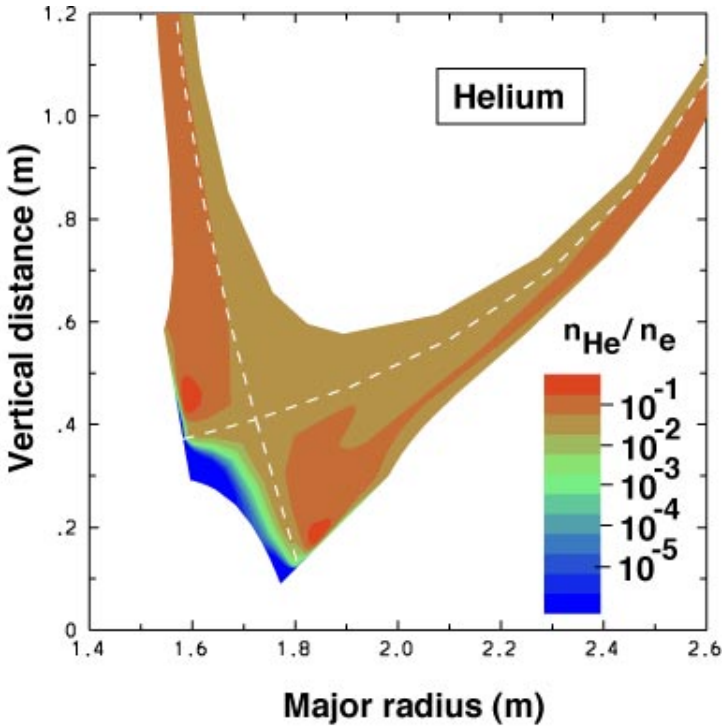




Heat flux

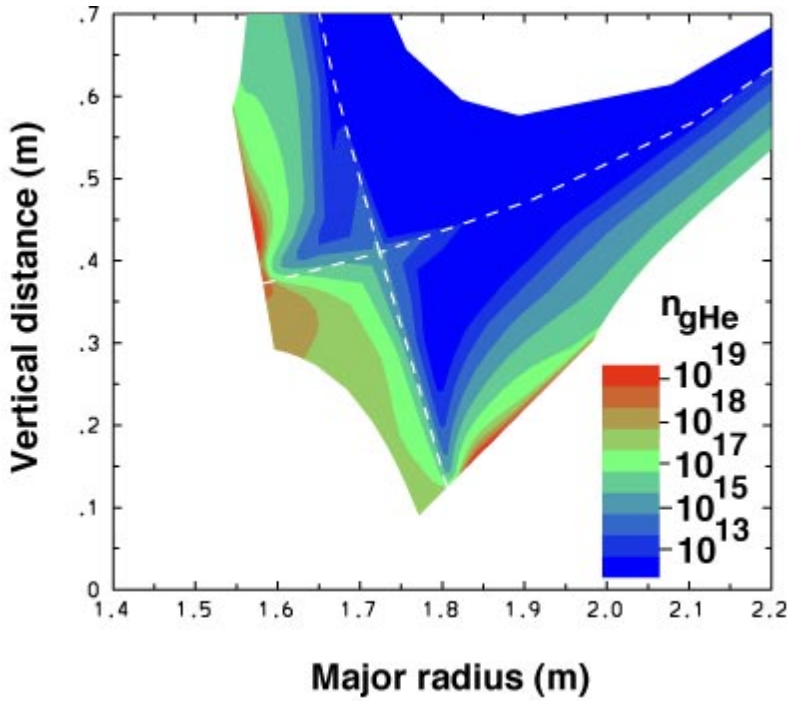
# Helium pumping in the private flux region appears adequate

- **Helium ion density at the core boundary of 2.5% is pumped in PF region; insensitive to albedo**

**Helium ion concentration**



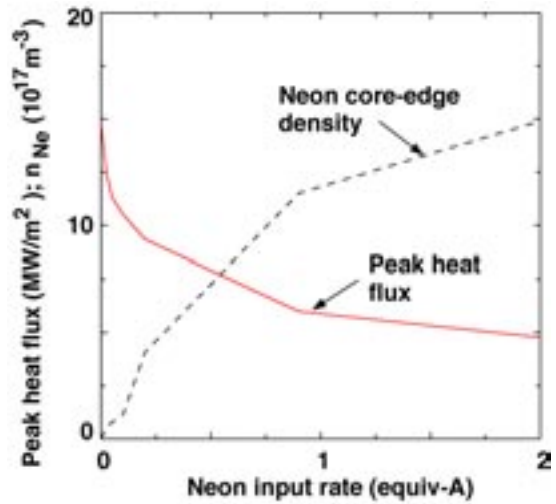

**Helium gas density**



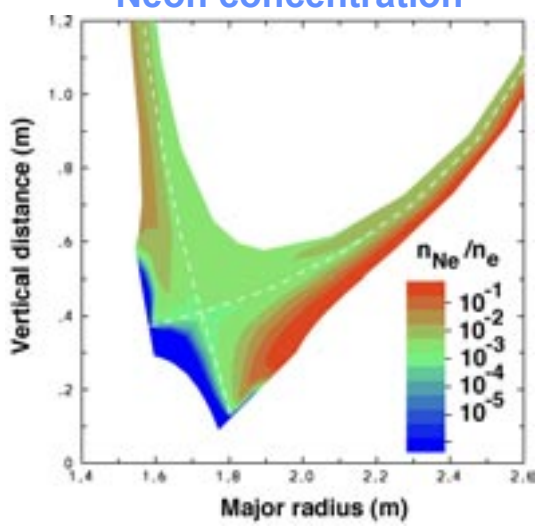
# Neon injection can induce partial detachment

- Neon is injected near the outer midplane as gas
- Neon gas is pumped in the private flux region with albedo=0.98
- Steady-state with heat flux < 6 MW/m$^2$

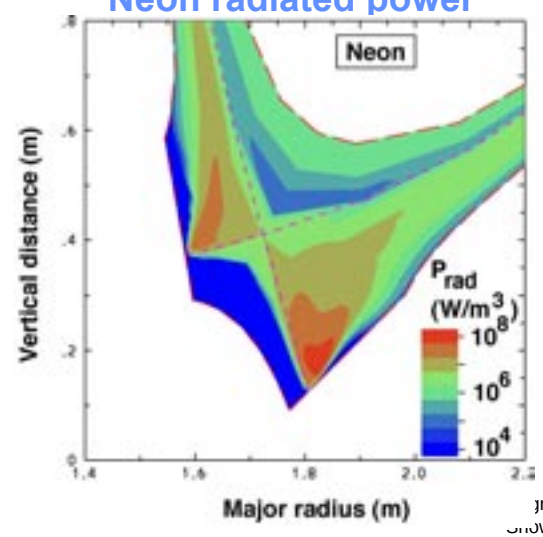
Peak heat flux & Ne core density




Neon concentration

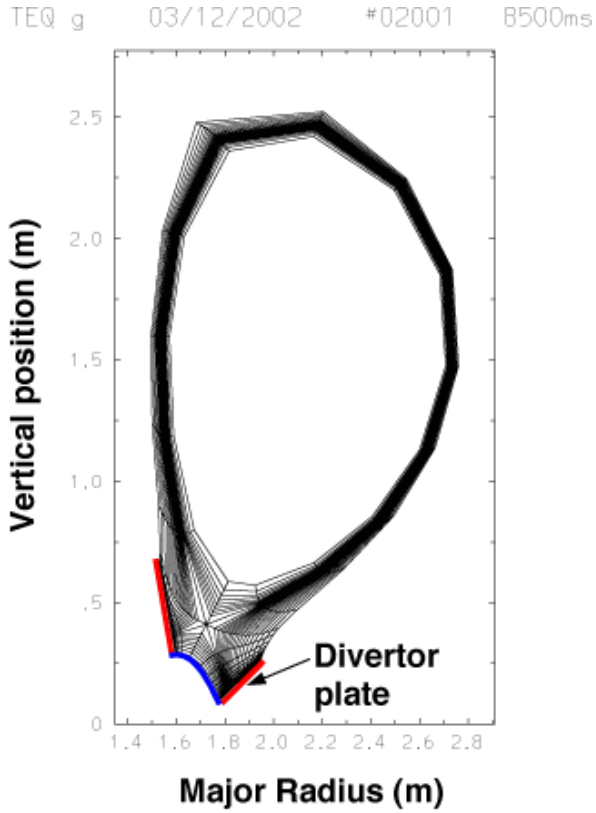



Neon radiated power

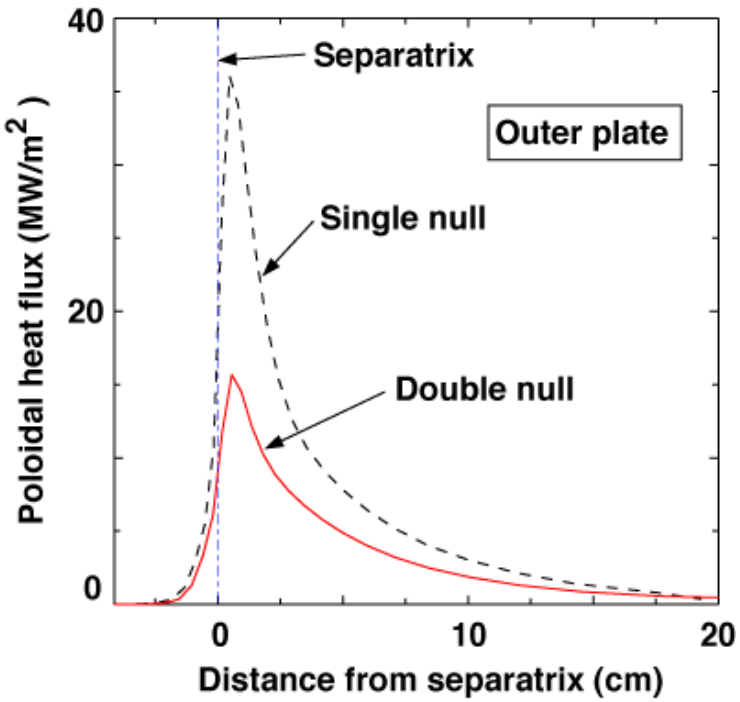


# A single-null FIRE variant has more than 2 times the peak heat flux of the double-null

- **The total power and other parameters are the same for single & double nulls**

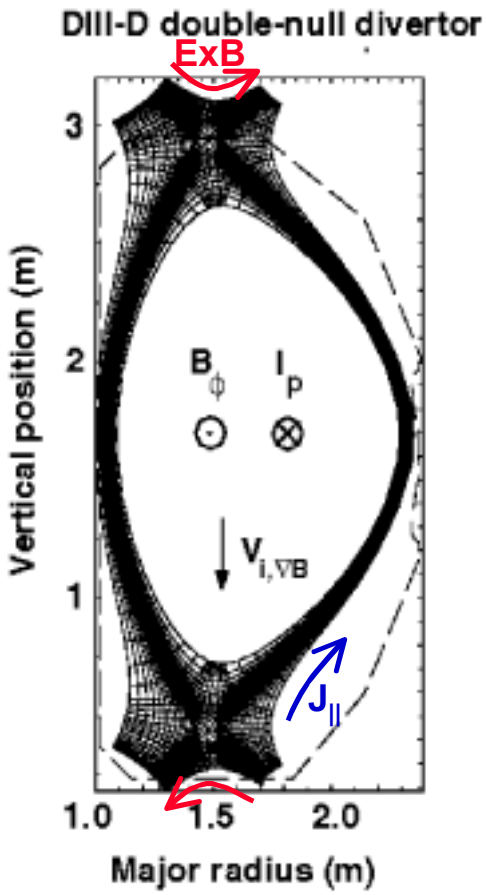



Heat flux profiles on outer divertor; no impurities



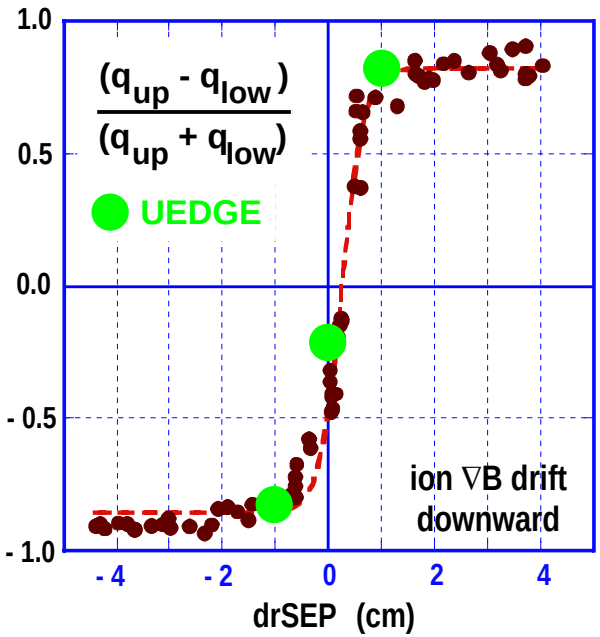
# Double-null imbalance can lead to sensitive power imbalance; DIII-D example (T. Petrie)

- UEDGE now treats range from single-null to double-null
- Double nulls reduce peak heat flux, but balance is delicate
- ExB flows and currents produce asymmetries
- Code reproduces measured DIII-D heat flux imbalance




(with M. Rensink)

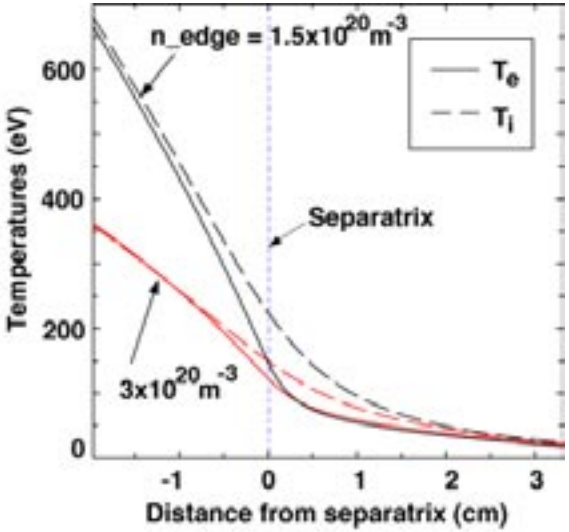
DIII-D heat-flux asymmetry between upper & lower divertors - T. Petrie




drSEP - distance between two separatrices at outer midplane

# Core-edge temperatures are inconsistent with high $T_{ped}$ unless $\chi$ is reduced to ~neoclassical

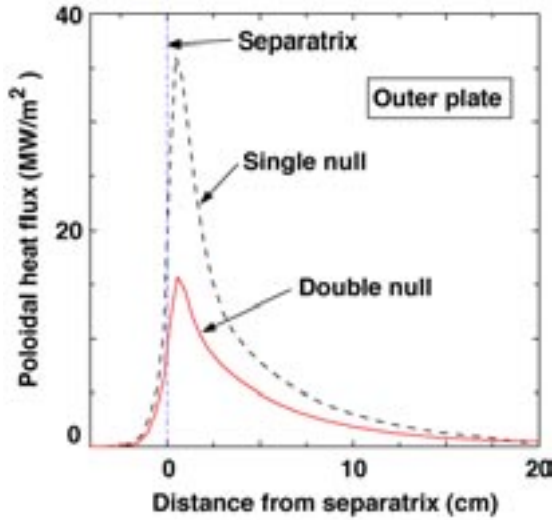
- Base-case core-edge temperatures are low (0.4 keV) for constant $D_\perp = 0.25$ and $\chi_i = \chi_e = 0.5\ m^2/s$
- Reduced diffusion through pedestal will help fix this, but limited by neoclassical diffusion of ~0.1 $m^2/s$ at 2 keV
- $E_r$ effect on neoclassical must be included
- Work on self-consistent pedestal region turbulence and transport is key (and ongoing)



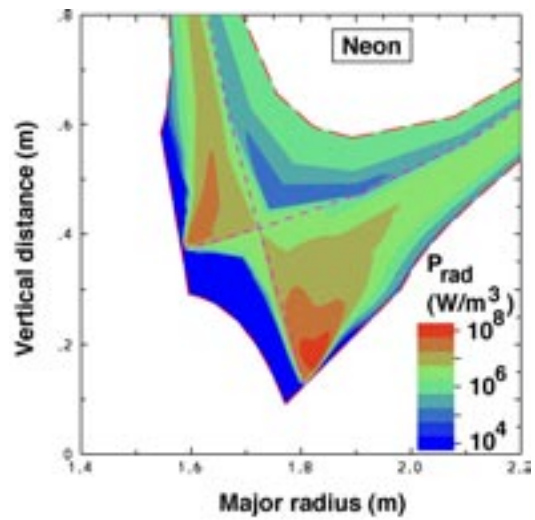

Midplane profiles

# A number of uncertainties remain

- Peak heat flux scales inversely with unknown anomalous transport coeff.
- Reabsorption of hydrogen radiation at high densities & stability of detachment
- Maintaining double-null power balance
- Redeposition/removal of beryllium to/from surfaces
- Consistency of pedestal temperature with good core confinement
- Size and impact of ELMs




Peak heat flux may be larger




Neon radiation for partial detachment can greatly reduce heat flux