Divertor regimes in NSTX

V. A. Soukhanovskii, R. Maingi, C. Bush, R. Raman, R. Bell, T. Biewer, B. P. LeBlanc, R. Kaita, H. W. Kugel, S. Paul, A. L. Roquemore, NSTX Research team

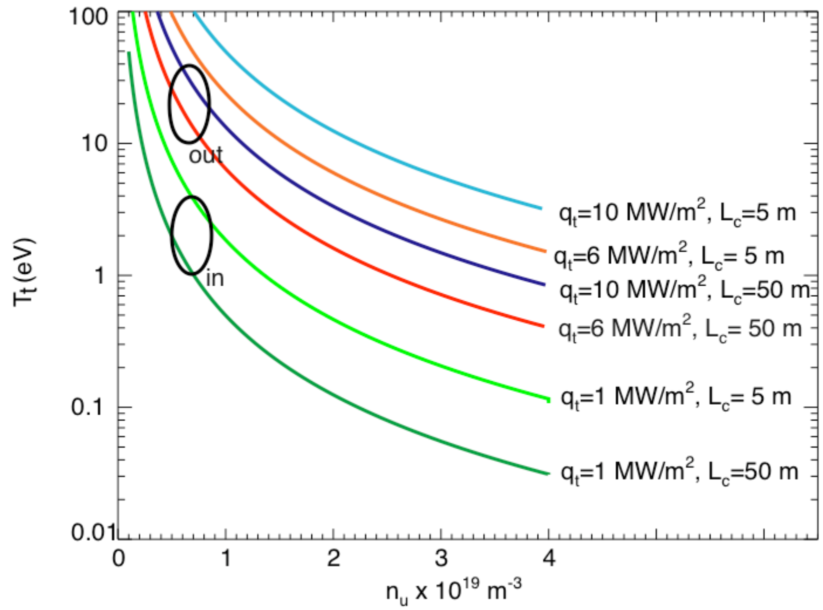
NSTX BP ET Meeting
05 April 2004
Princeton, NJ

Experiment goals

- Obtain database of divertor data in LSN D_2 LFS fuelded discharges for a range of n_e and P_{in}
- Identify sheath limited, high recycle and detached regimes and/or their signatures
- Develop means to achieve detachment (D2, neon, gas injection locations) and identify detachment threshold for D_2 and neon LFS fueled plasmas
- Assess main plasma parameters during detachment (confinement, impurities, fueling)

- Experiment has clear deliverable research result
- Experiment is called for by NSTX 5 Year research plan
- Results to be presented at PSI-16 conference in May 2004 (abstract accepted)

Divertor two point model suggests detachment



P. C. Stangeby, *The plasma boundary of Magnetic Fusion Devices*, IoP Publishing, Bristol & Philadelphia, 2000

$$2\, n_t\, T_t = n_u\, T_u$$

$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2}\frac{q_{||}\, L_c}{\kappa_0}$$

$$q_{||} = \gamma\, n_t\, T_t\, c_{St}$$

$$\frac{14}{3} c_Z L_Z n_u^2 L > q_u$$

Sheath-limited (linear) regime:

$$n_t \simeq n_u;\ T_t \simeq n_u^{-2/3};\ T_u \simeq n_u^{-2/3};\ \Gamma_n \simeq n_u;\ n_t \neq q_u;\ T_t \simeq q_u^{2/3};\ T_u \simeq q_u^{2/3};\ \Gamma_n \neq q_u$$

High-recycling (flux-limited) regime:

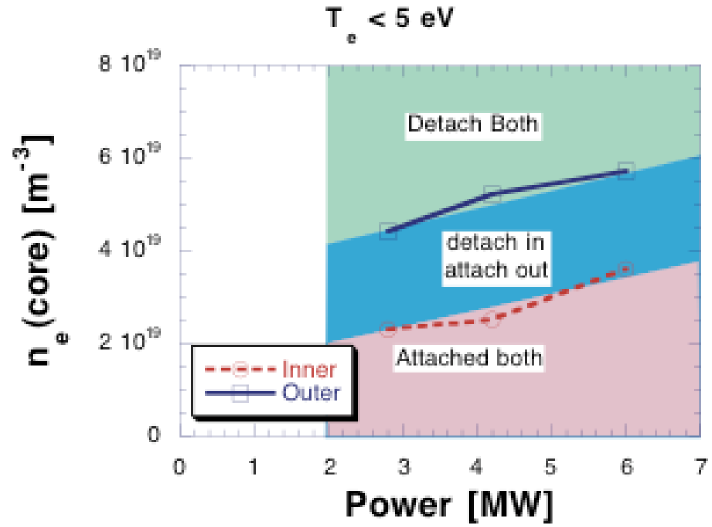
$$n_t \simeq n_u^3;\ T_t \simeq n_u^{-2};\ T_u \neq n_u;\ \Gamma_n \simeq n_u^3;\ n_t \neq q_u^{-8/7};\ T_t \simeq q_u^{10/7};\ T_u \simeq q_u^{2/7};\ \Gamma_n \simeq q_u^{-8/7}$$

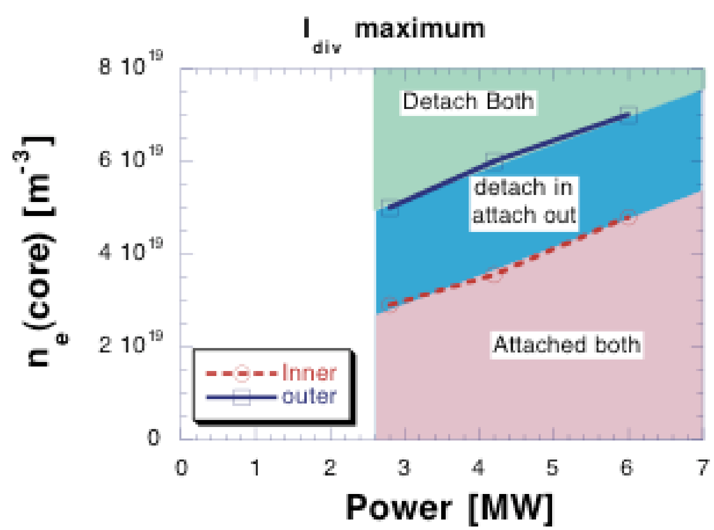
Detached regime:

$$n_t \text{ down with } n_u;\ T_t \text{ down with } n_u;\ T_u \neq n_u;\ \Gamma_n \text{ up with } n_u$$

$$n_t \text{ up with } q_u;\ T_t \text{ up with } q_u;\ T_u \simeq q_u^{2/7};\ \Gamma_n \text{ down with } q_u$$

UEDGE predicts detachment (G. Porter, N. Wolf (LLNL))





For guidance purposes only, improvements possible

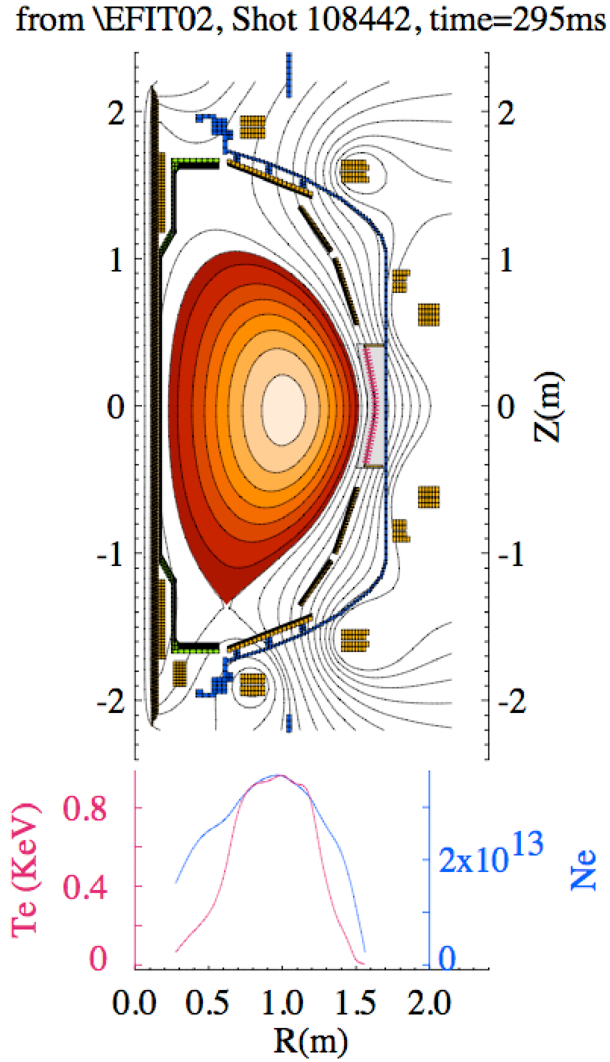
- Shot 109053 (LSN HFS-fueled H-mode)
- Radial ion transport $D_{\perp} = 1\ m^2 / s$, $\chi_i = \chi_e = 3\ m^2 / s$
- Recycling is 1 on divertor plates
- Pumping outer wall
- Carbon included with phys. & chem. sputtering and anom. radial transport
- Scan core density and heating power
- Detachment definition: 1/ $T_e^{div} < 5$ eV 2/ I_{div} saturates with upstream density

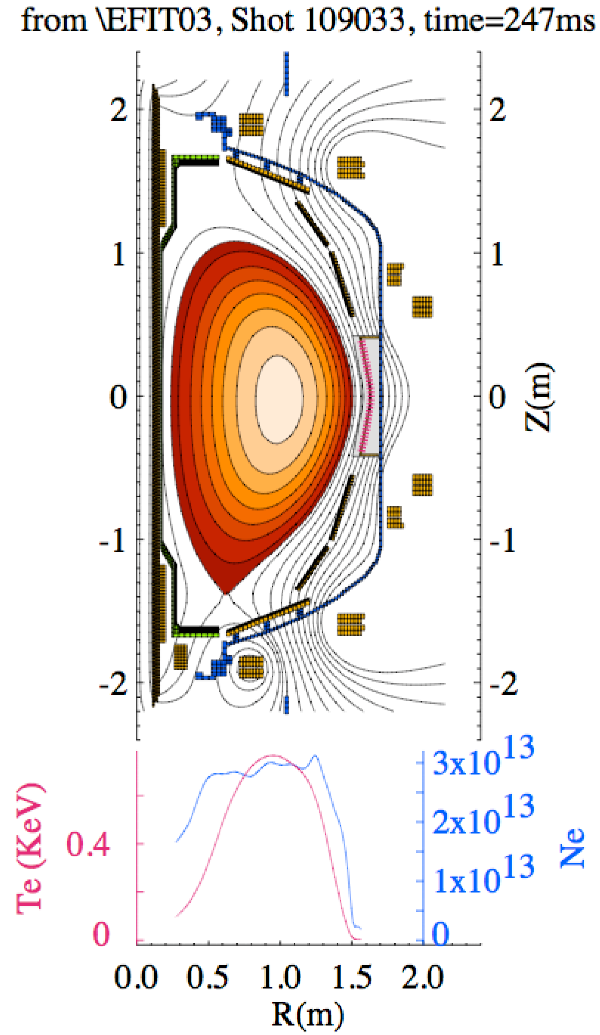
NSTX divertor data summary

- In HFS D_2 fueled plasmas:
  - high inboard flux expansion, inboard heat flux weakly depends on input power and density
  - Outer divertor heat flux and D_α intensity ($\sim \Gamma_i$) are non-linear functions of input power and density
  - Divertor D_α in/out asymmetry is density dependent
- In LFS D_2 fueled plasmas
  - no IRTV for the analyzed shots
  - Divertor D_α in/out asymmetry is density dependent (different than in HFS D_2 fueled plasmas)
- Divertor D_α in/out asymmetry reverses during transient events
- In ohmic plasmas D_α in/out asymmetry always less than 1

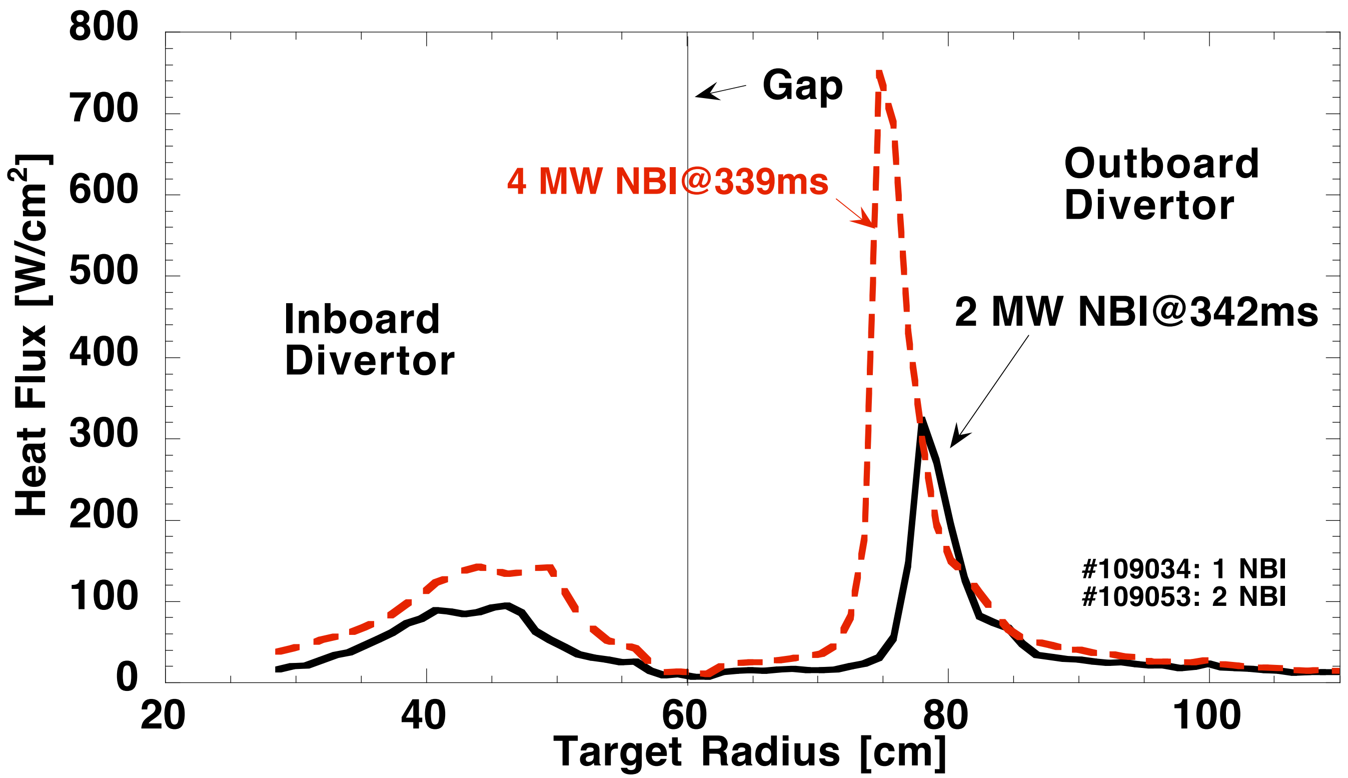
Present thinking - inboard divertor almost always detached, outboard divertor is in high recycling regime

Magnetic configuration for analyzed LFS and HFS fueled plasmas





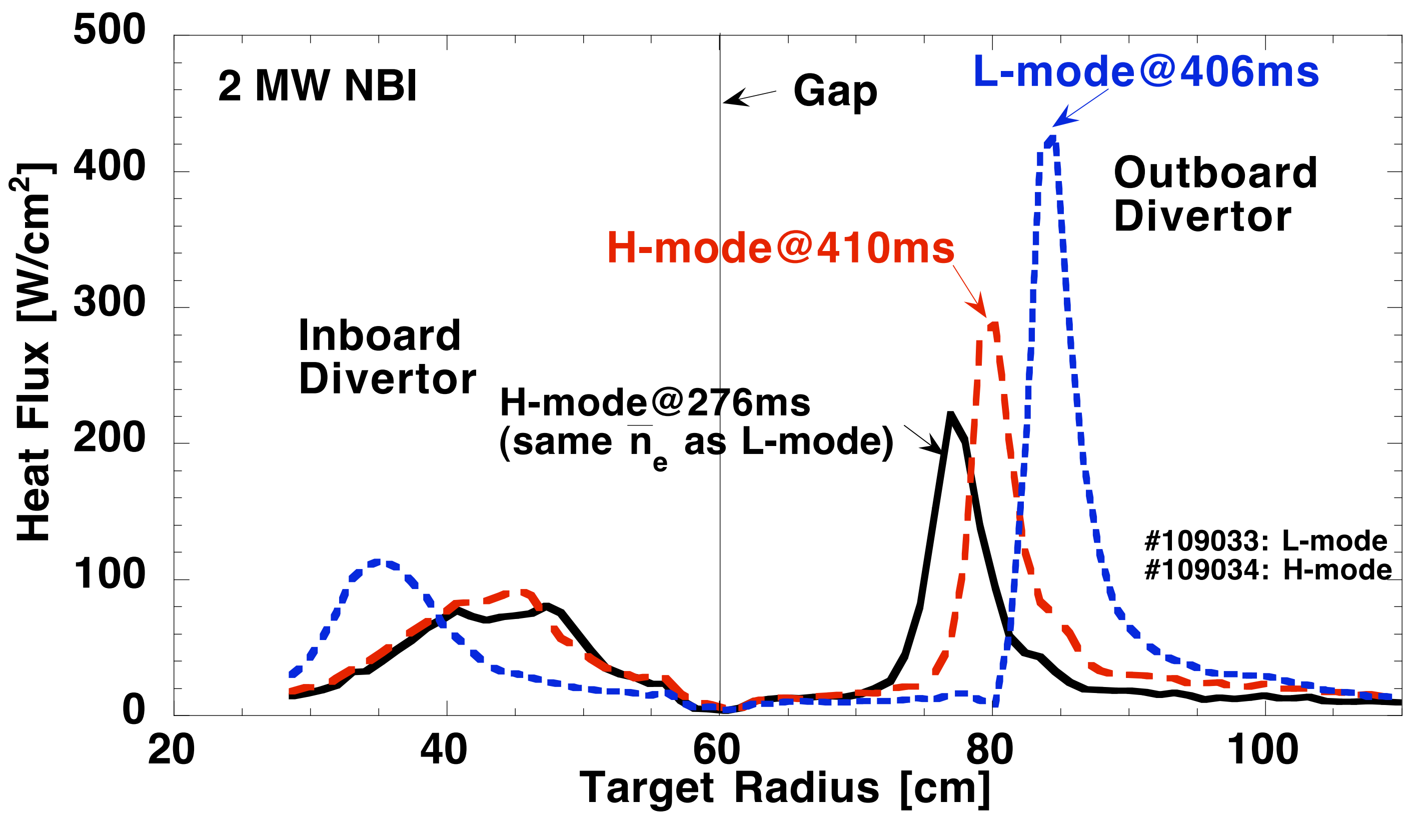
IRTV: outer divertor peak heat flux increases non-linearly with heating power



R. Maingi (ORNL)

- q_{in}/q_{out}= 2-3 due to higher inboard flux expansion
- Heat flux equilibration time τ_{eq}~ 100 ms
- Power accountability: up to 70 % of P_{NBI} measured in divertor

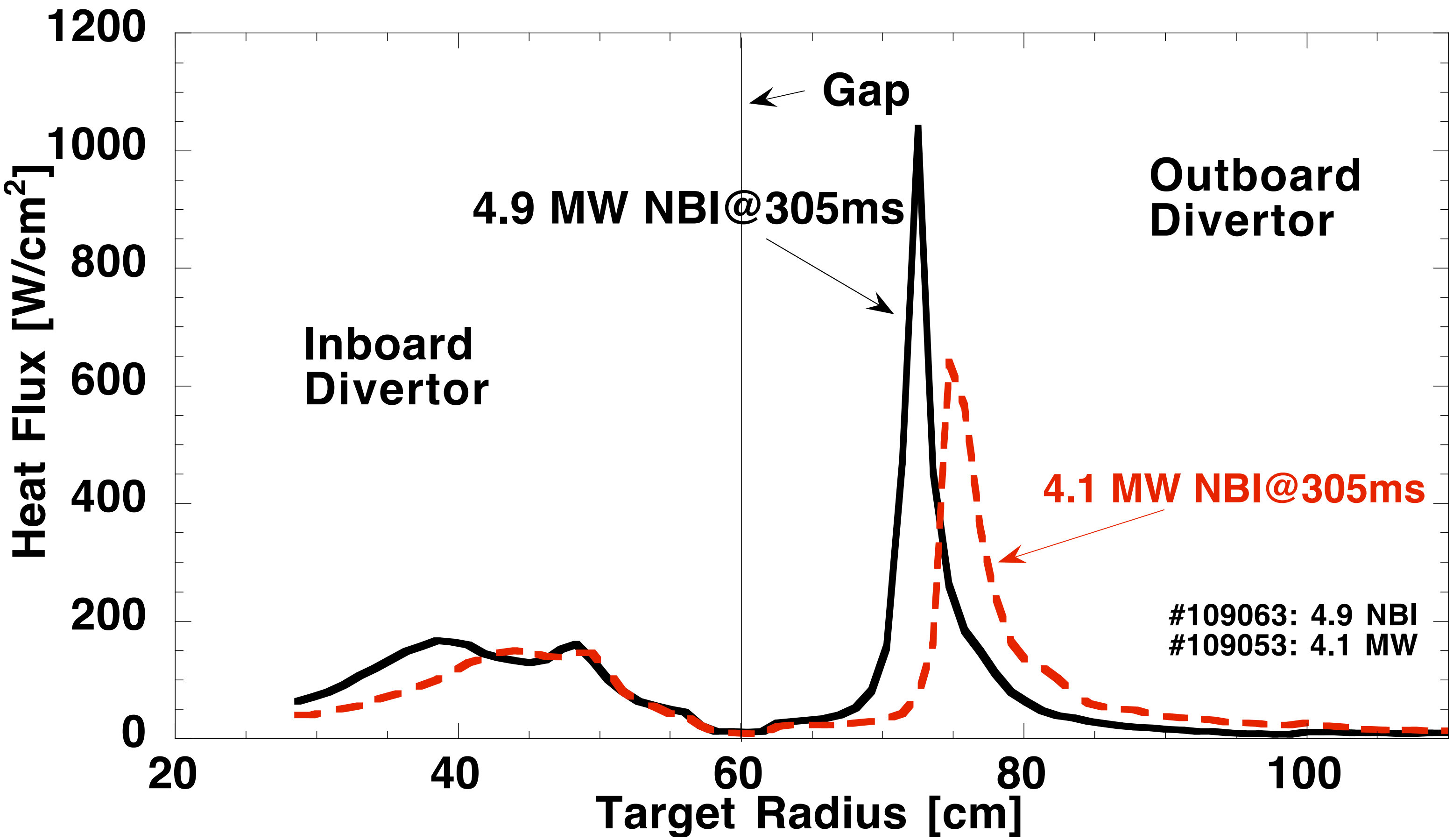
Higher outer divertor heat flux in L-mode vs H-mode



R. Maingi (ORNL)

- Divertor heat flux independent of gas injection location

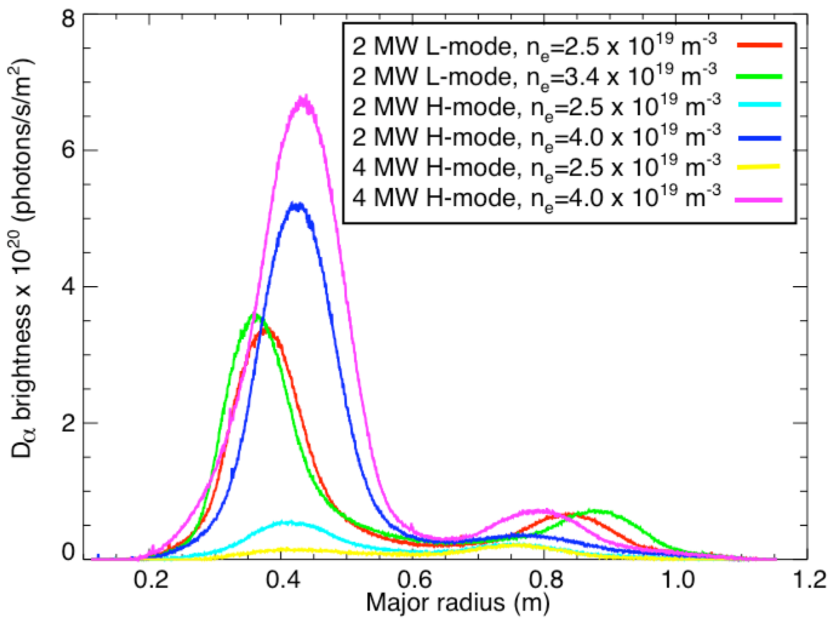
Highest peak heat flux observed ~ 10 MW/m²

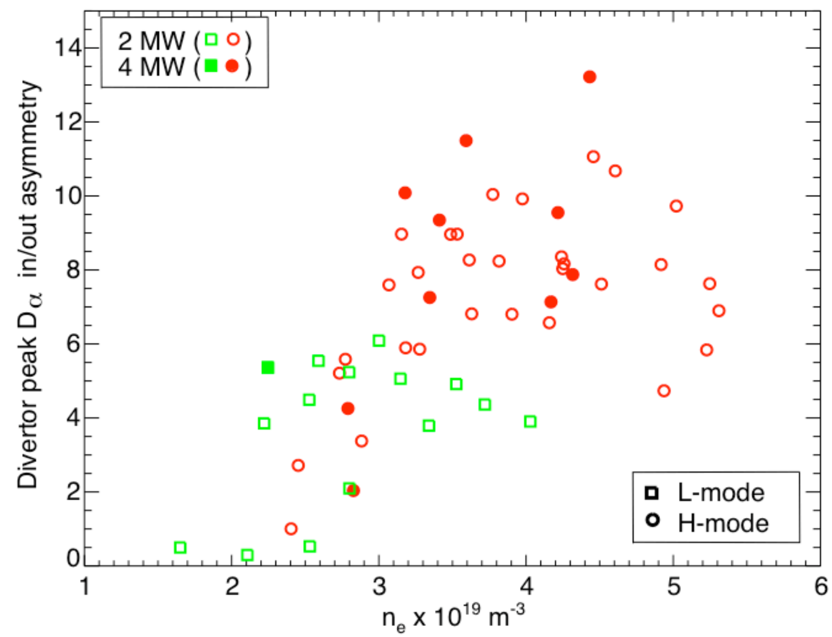


R. Maingi (ORNL)

- Heat flux mitigation will be required for t_{pulse} ~ 3 s

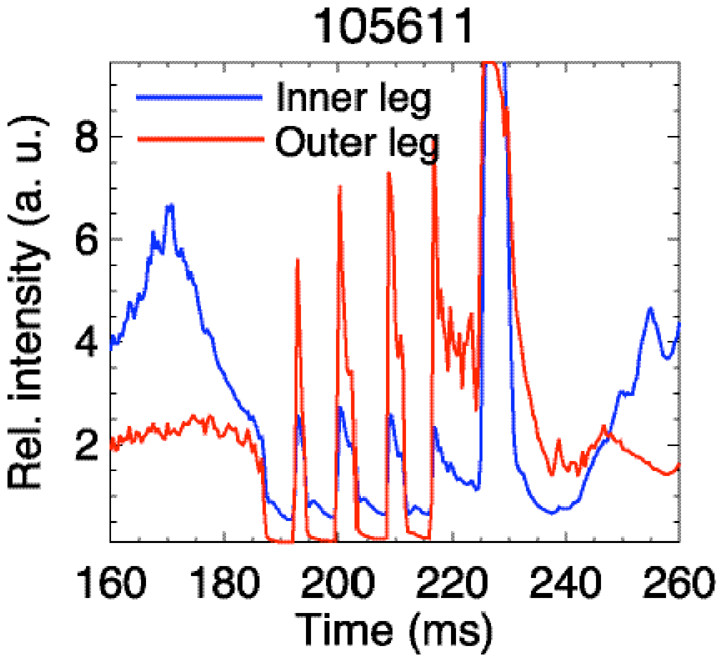
Divertor D_α in/out asymmetry in HFS-fueled plasmas

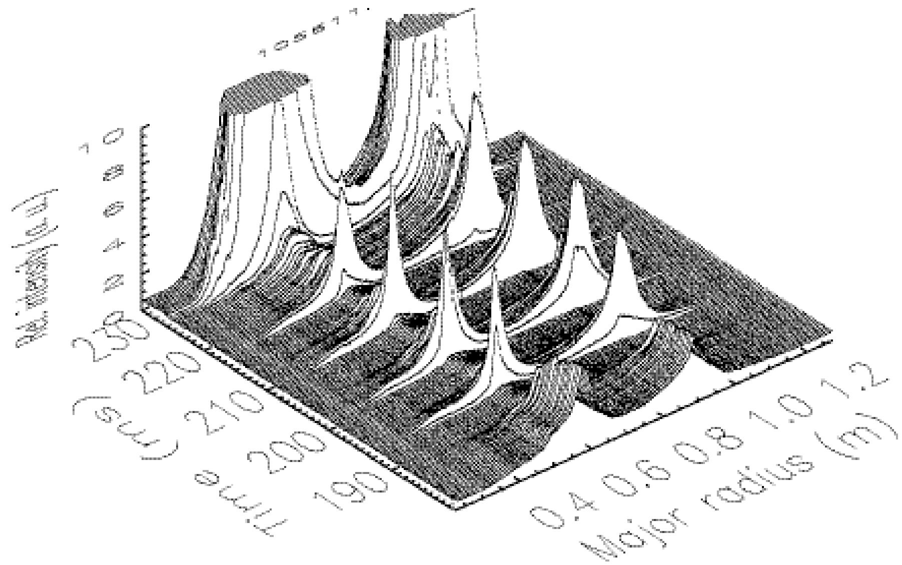


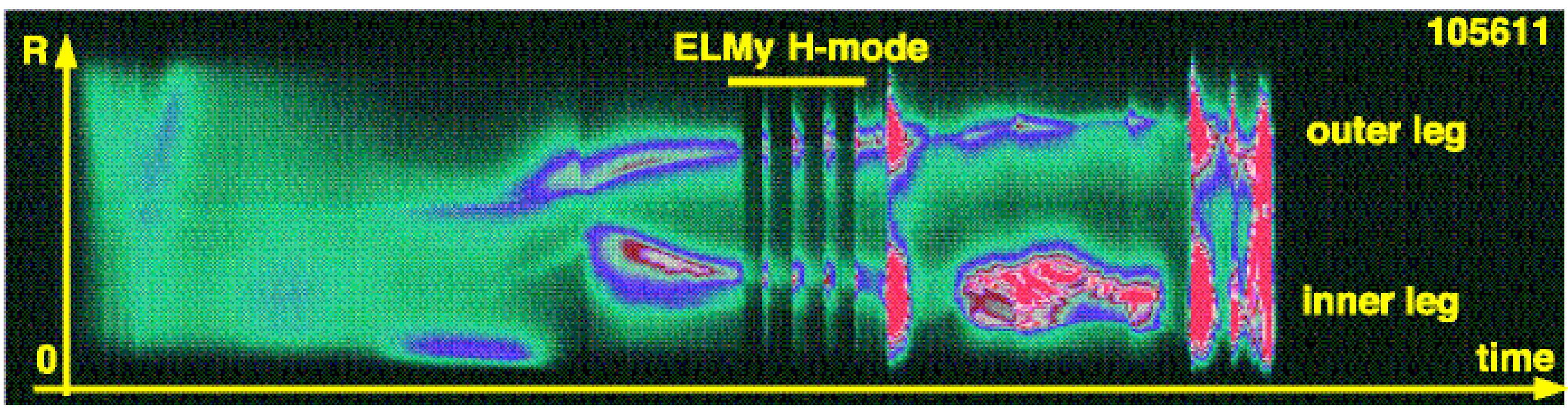


- **Asymmetry A = 4 - 6 in L-mode, A = 7 - 12 in H-mode** $A_{D_\alpha} = B_{in}/B_{out}$
- **Asymmetry A < 1 at low density**
- **Asymmetry reverses during transient heat pulses (from IRE's)**
- **Consistent with inboard divertor target detachment (outboard target attached) (??)**

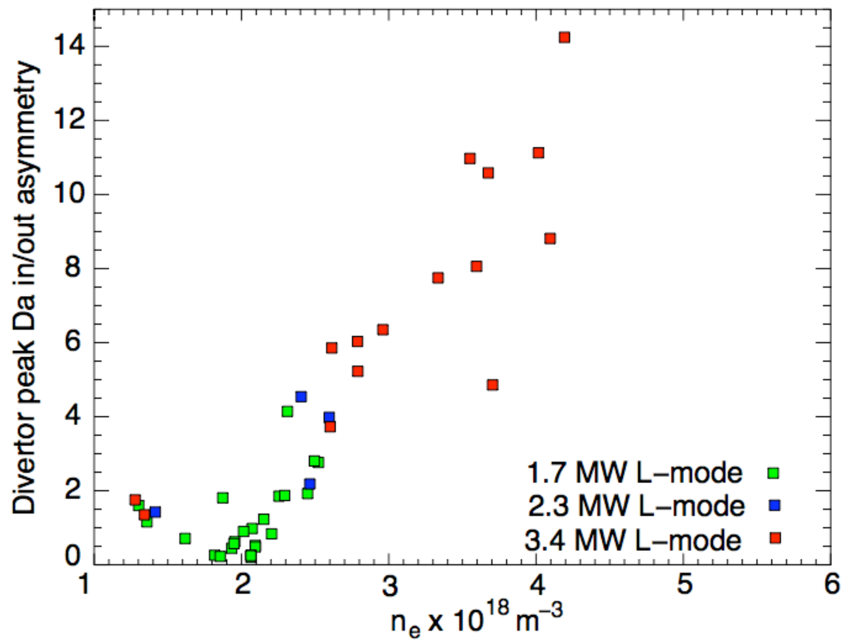
Divertor D_α asymmetry reverses during transient heat pulse events

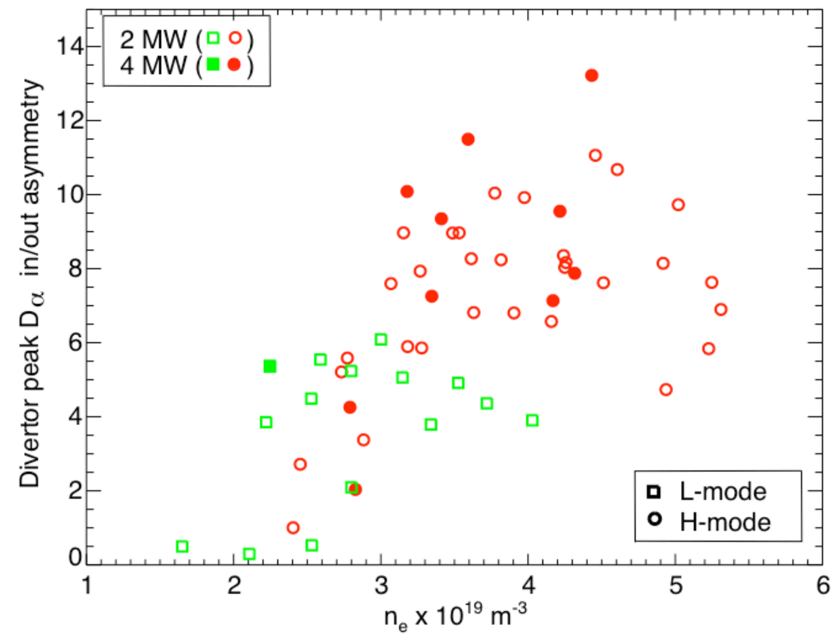






Divertor D_α in/out asymmetry in LFS-fueled plasmas



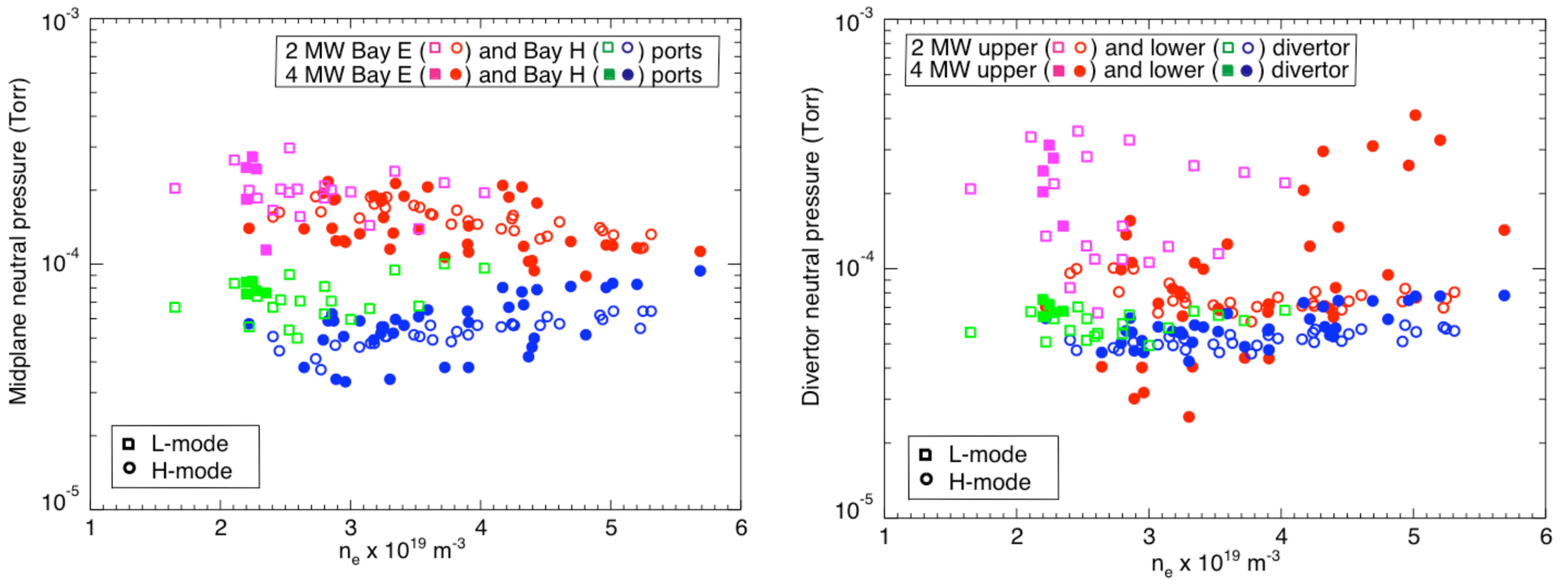


LFS-fueled **compare to** **HFS-fueled**

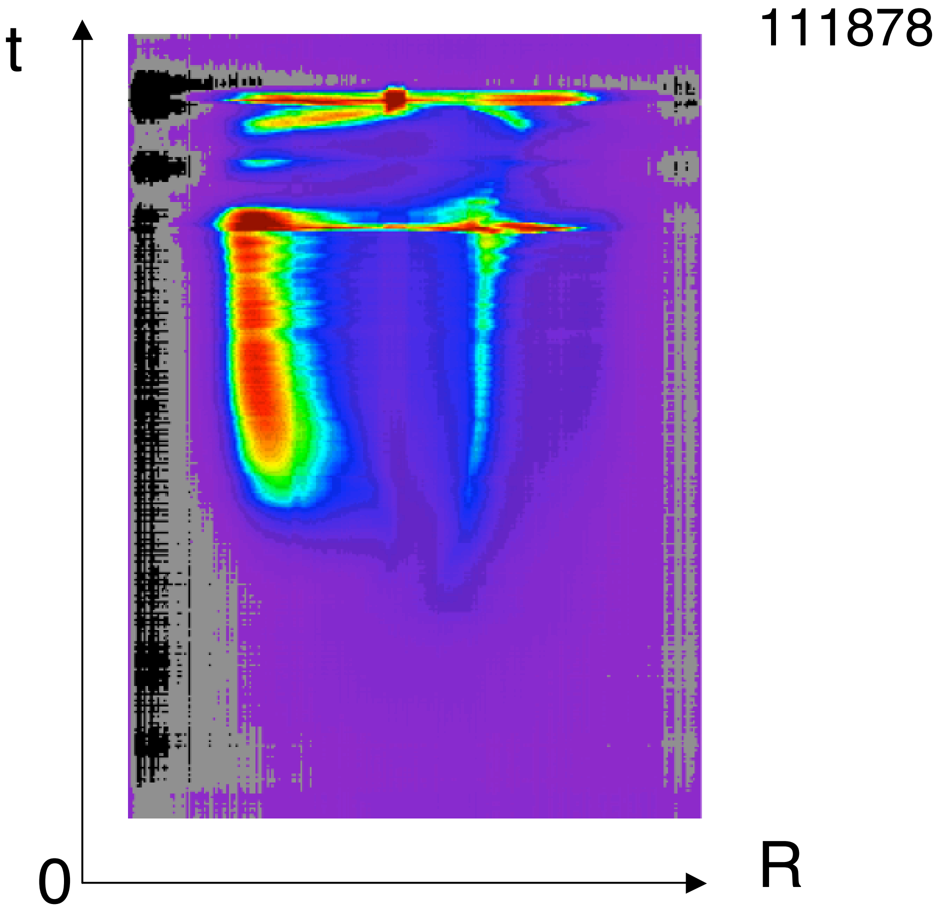
- Asymmetry A < 1 at low density
- In HFS-fueled L-mode plasmas A > 1 at 2 x 10^{19} m^{-3} and saturates
- In LFS-fulede L-mode plasmas A > 1 at 2 x 10^{19} m^{-3} and rises

$$A_{D_\alpha} = B_{in}/B_{out}$$

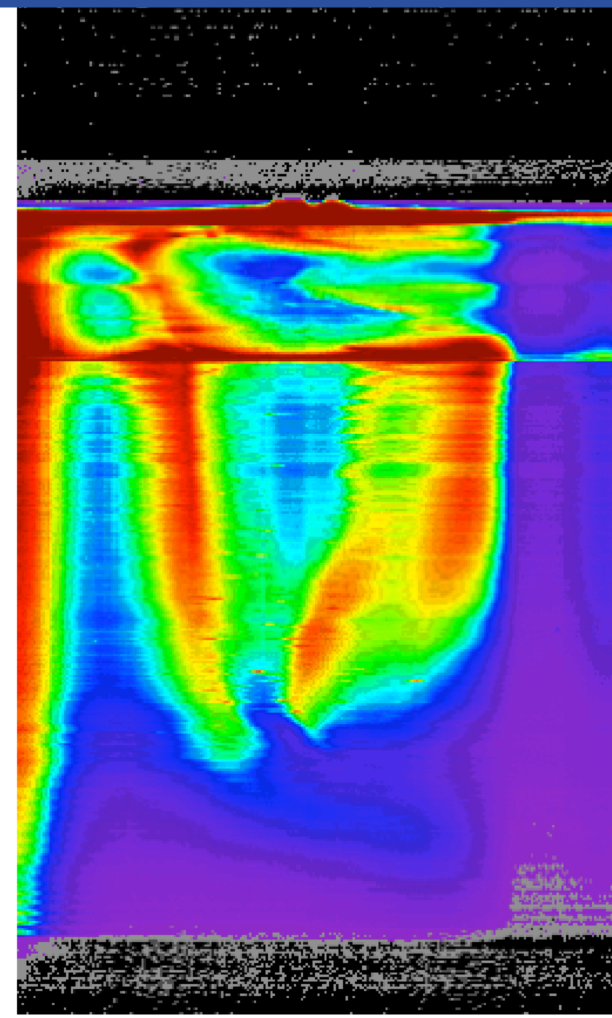
Midplane and divertor neutral pressure data are perplexing



New 1D CCD array will alow simultaneous observations of divertor D_α and $D\gamma$



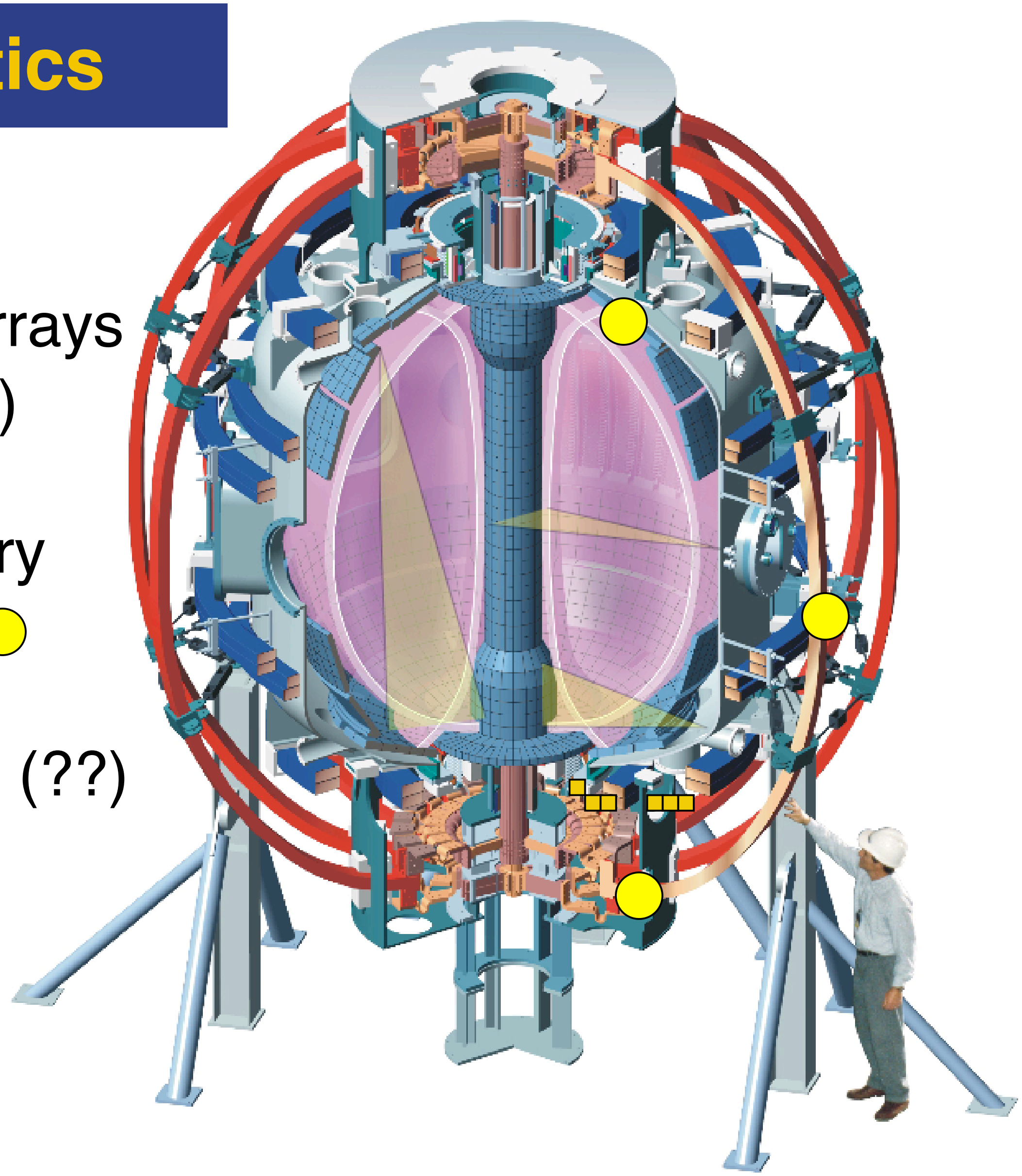
D_α brightness



C II brightness

Essential Diagnostics

- D_α, D_γ, CII, CIII 1D CCD arrays
- IRTV (l. divertor, midplane)
- Divertor tile probes ▫
- Core and divertor bolometry
- Neutral pressure gauges ●
- CHERS, MPTS
- UCSD reciprocating probe (??)
- Plasma TV cameras
- Fast divertor camera



Experiment plan

Use NBI-heated LSN discharge 108442 as a template
(Ip = 0.9 MA, B_t=0.42 T, 1-3 NBI src, LFS fueling from Injector # 1, 2 (for density control), Injector # 3 for neon)

- Re-establish L-mode discharge 108442 (2 shots)
- Ohmic L-mode plasma with n_e = 2 and 4-6 x 10^{18} m^{-3} (3 shots)
- L-mode 1 NBI src with n_e = 2, 4, 6 x 10^{18} m^{-3} (4 shots)
- L-mode 2 NBI src (2nd src early) with n_e = 2, 4, 6 x 10^{18} m^{-3} (4 shots)
- L-mode 3 NBI src (2nd and 3d src early) with n_e = 2-3, 5-6 x 10^{18} m^{-3} (4 shots)
- Inject neon in L-mode 1 NBI src with n_e = 2-6 x 10^{18} m^{-3} (5 shots)

Use 109033 (HFS-fueled L-mode plasma) as a template

- Inject D_2 from Injector 2 (10 shots) with 1, 2, 3 NBI src

Future work

- Reversed ∇B direction plasma
- ST geometry effects on commonly observed divertor regimes
- Detachment in DN divertor
- Detachment in Helium plasmas
- Correlation of turbulence in inboard and outboard SOL and divertor detachment
- Divertor detachment in HHFW-heated plasmas
- Detachment in long high power density H-mode plasmas