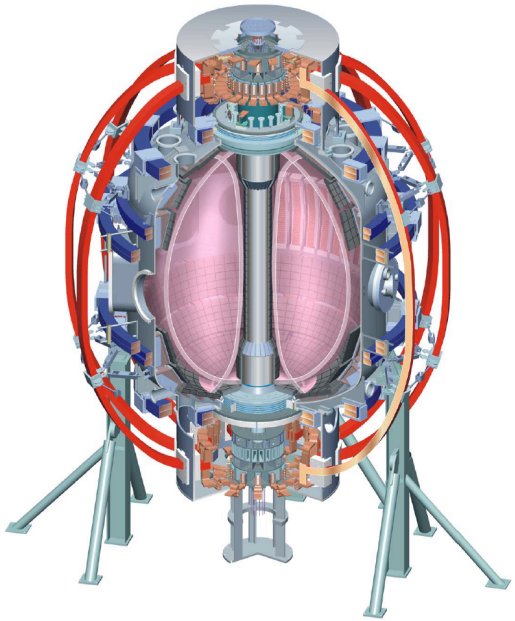
Supported by Office of Fusion Energy Sciences (Excellent Science Attractive Energy) Office of Science

# XP 708: Divertor heat flux reduction and detachment in highly shaped plasmas

**V. A. Soukhanovskii**



*Acknowledgments:*
R. Maingi, D. Gates, J. E. Menard, R. Raman, C. E. Bush, R. E. Bell, R. Kaita, H. W. Kugel, C. J. Lasnier, B. P. LeBlanc, S. F. Paul, A. L. Roquemore

**NSTX Physics Meeting**
**25 June 2007**
**Princeton, NJ**

ORNL PPPL Princeton Plasma Physics Laboratory LLNL NSTX

# Summary of 2 hr run on 21st June 2007

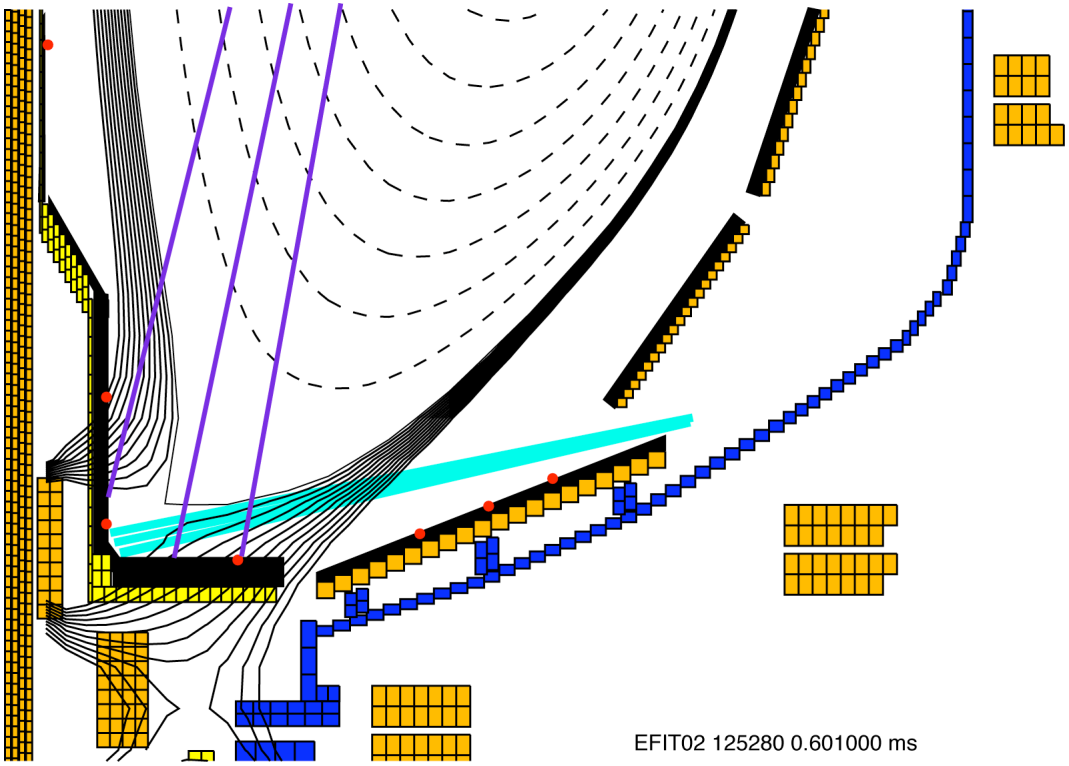
- Used 1 MA 6 MW fiducial with rtEFIT-controlled DRSEP set to -1.2 cm

- Since divertor $q_{peak}$ scales with $P_{SOL}$ ($P_{NBI}$) and $I_p$, obtained data in H-mode shots
  - ✓ 1.0 MA 4 MW NBI reference and w/divertor $D_2$ puffing
  - ✓ 1.0 MA 6 MW NBI reference and w/divertor $D_2$ puffing
  - ✓ 1.2 MA 6 MW NBI w/divertor $D_2$ puffing

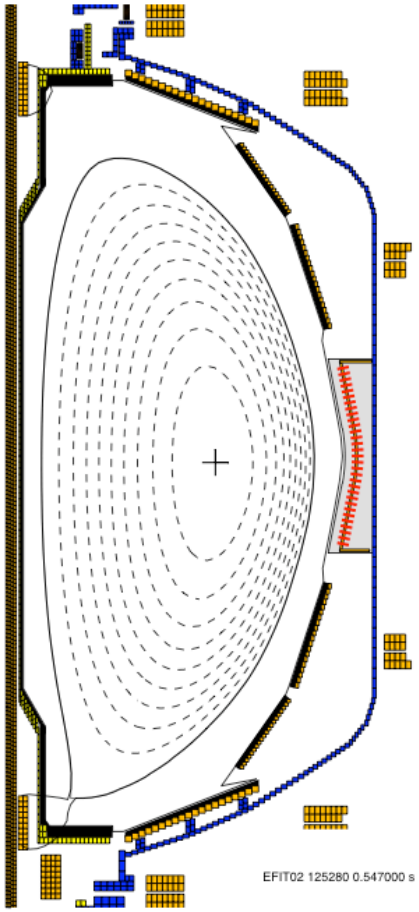
- It appears that partial OSP detachment was obtained in all three cases
  - ✓ Divertor peak heat flux clearly reduced at OSP, profile broadened
  - ✓ Radiated power increased x 2 in outer leg ($P_{loss}$)
  - ✓ Lower divertor neutral pressure increased (momentum loss)
  - ✓ Clear signs of volume recombination, low $T_e$ and high $n_e$ from Balmer high-*n* spectra
  - ✓ Core confinement and $\beta$ practically unaffected!
  - ✓ Core radiated power *reduced* (metal influx reduced)

# Proper plasma and diagnostic configurations were essential for XP success

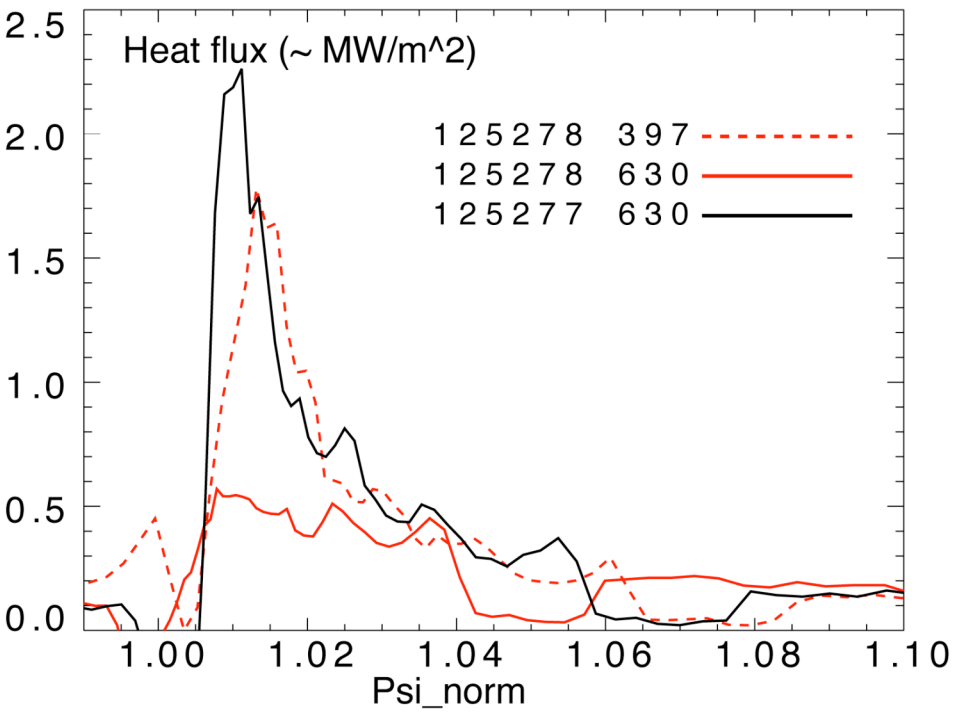
- **rtEFIT control enabled critical parameter control (DRSEP, RVSOUT, GAP)**
- **Multi-diagnostic configuration was necessary to measure core and SOL/divertor parameters simultaneously**
  - ✓ IR cameras (upper, lower divertors)
  - ✓ Divertor bolometry
  - ✓ Tile Langmuir probes
  - ✓ Spectroscopy (Divertor Dα, Dγ, VIPS 2)
  - ✓ Neutral pressure gauges

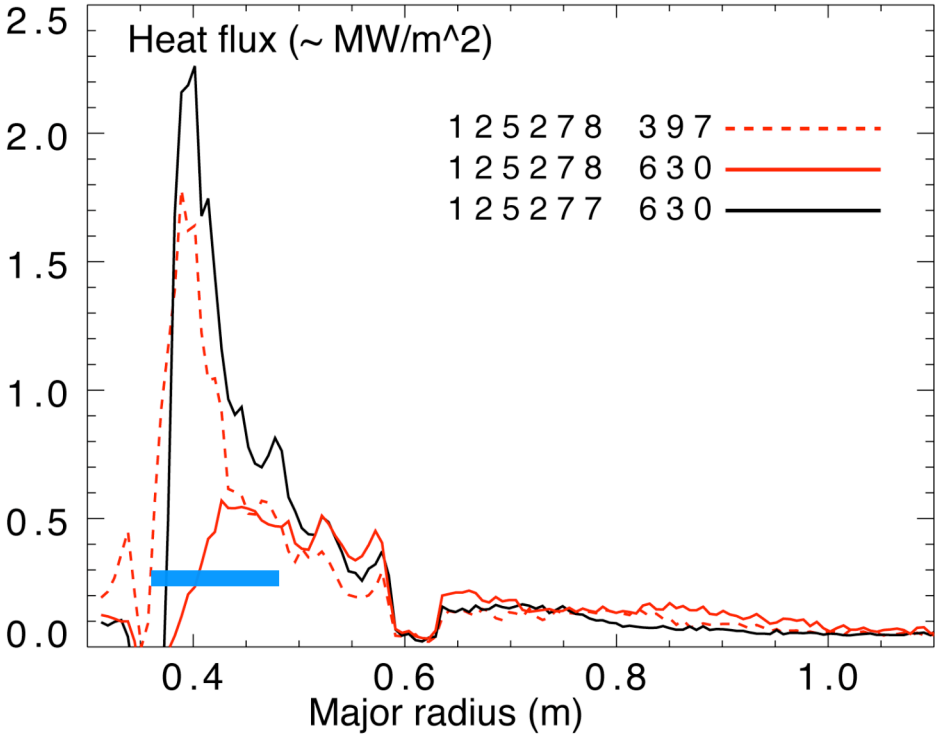



| | |
|---|---|
| shot | 125280 |
| time | 0.547000 |
| chi**2 | 153.899 |
| Rout(m) | 0.854 |
| Zout(m) | -0.096 |
| a(m) | 0.591 |
| elong | 2.350 |
| utri | 0.411 |
| ltri | 0.787 |
| indent | 0.000 |
| V (m**3) | 12.326 |
| A (m**2) | 2.481 |
| W (MJ) | 0.266 |
| betaT(%) | 18.415 |
| betaP | 0.990 |
| betaN | 4.806 |
| li | 3.832 |
| Li | 0.554 |
| error(e-4) | 10000.000 |
| q1 | 14.308 |
| q95 | 8.164 |
| dsep(m) | 0.079 |
| Rm(m) | 1.000 |
| Zm(m) | 1.000 |
| Rc(m) | 0.937 |
| Zc(m) | -0.049 |
| betaPd | 0.947 |
| betaTd | 17.613 |
| Wdia(MJ) | 0.254 |
| Ipmeas(MA) | 1.017 |
| BT(0)(T) | -0.440 |
| Ipfit(MA) | 0.995 |
| Rmidin(m) | 0.264 |
| Rmidout(m) | 1.445 |
| gapin(m) | 0.079 |
| gapout(m) | 0.122 |
| gaptop(m) | 0.294 |
| gapbot(m) | 0.119 |
| Zts(m) | 100.000 |
| Rvsin(m) | 0.000 |
| Zvsin(m) | 0.000 |
| Rvsout(m) | 0.279 |
| Zvsout(m) | -1.470 |
| Rsep1(m) | 0.390 |
| Zsep1(m) | -1.484 |
| Rsep2(m) | 0.412 |
| Zsep2(m) | 1.406 |
| psib(Vs/R) | -0.017 |
| elongm | 2.428 |
| qm | 1.000 |
| nev1(e19) | 0.000 |
| nev2(e19) | 0.000 |
| nev3(e19) | 0.000 |
| ner0(e19) | 0.000 |
| n/nc | -0.010 |
| dRsep | -0.007 |
| qmin | 2.310 |
| rhoqmin | 0.441 |



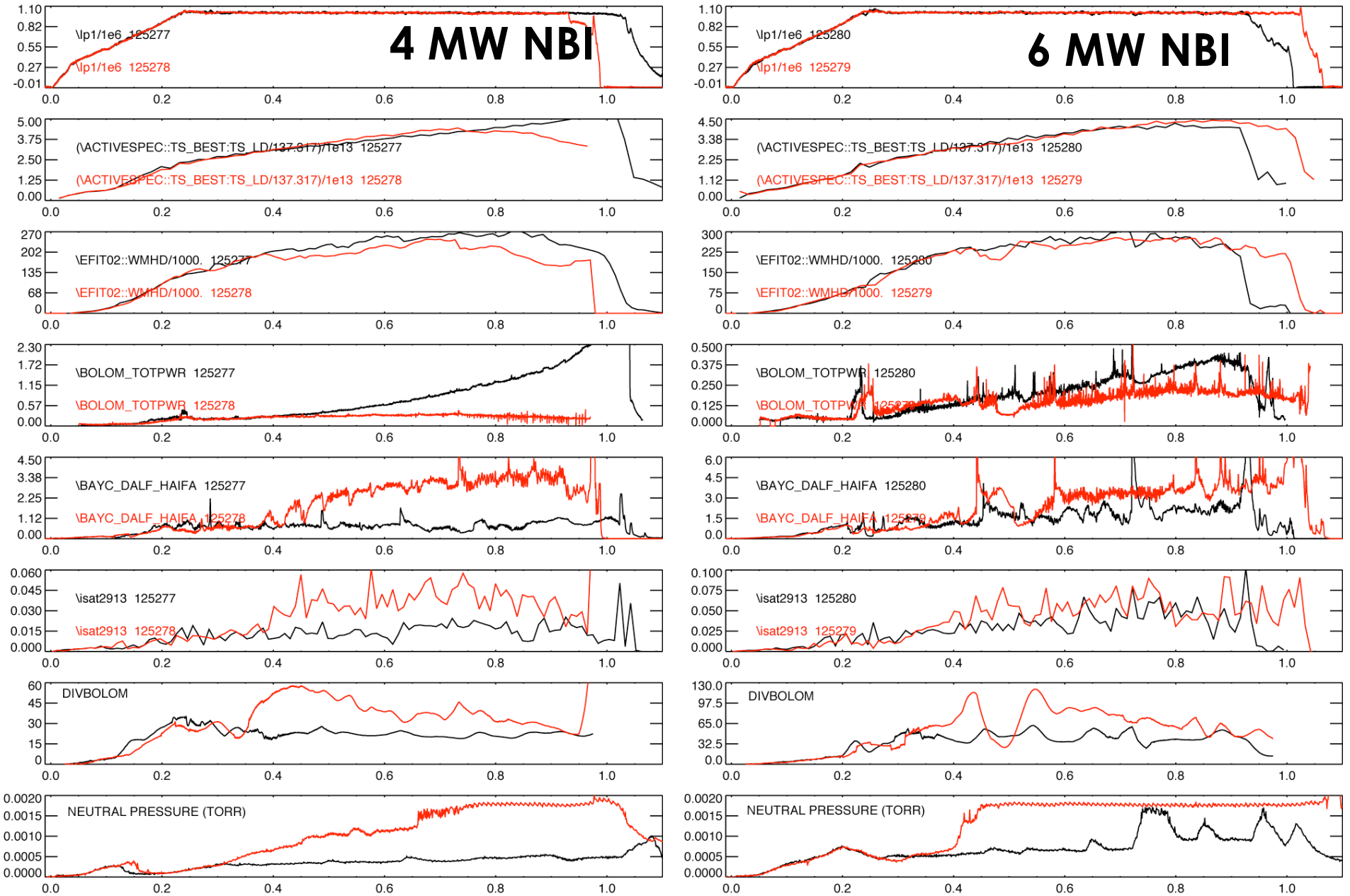
# In PDD regime divertor peak heat flux reduced by x 3-4, heat flux profile broadened



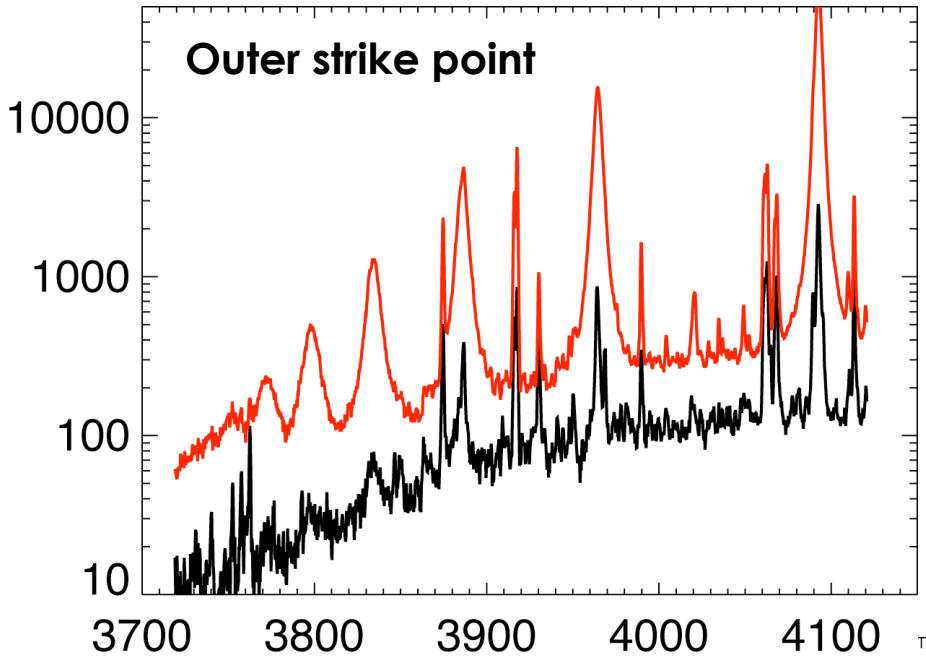



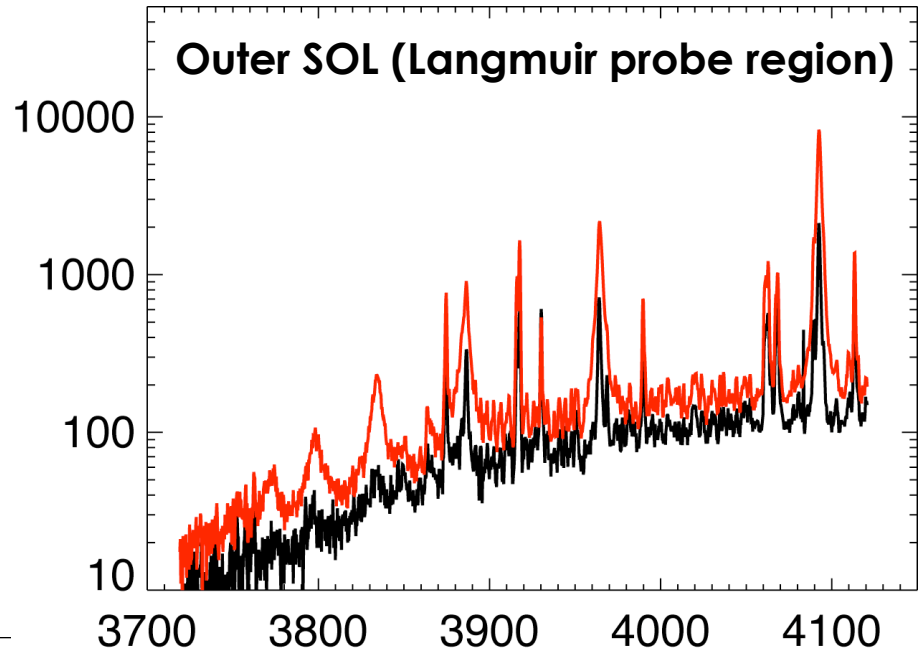

- Shown are divertor heat flux profiles for 1 MA, 4 MW NBI plasmas
- Peak *q* reduces over ~ 10 cm ($\psi_n$ ~ 0.01)
- Further out of PDD region, SOL remains in high-recy regime

# PDD regime is suggested by many diagnostics

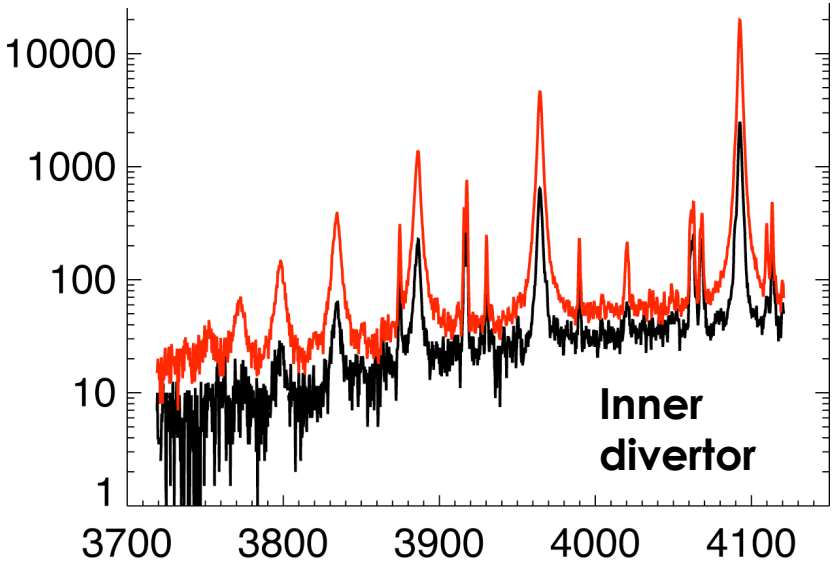


# Volume recombination, high $n_e$ and low $T_e$ at OSP are evident from spectra observed during PDD




**125277, 630 ms**
**125278, 630 ms**



# Back-up slides

# NSTX FY08 milestone, ST development path and divertor physics studies motivate the XP

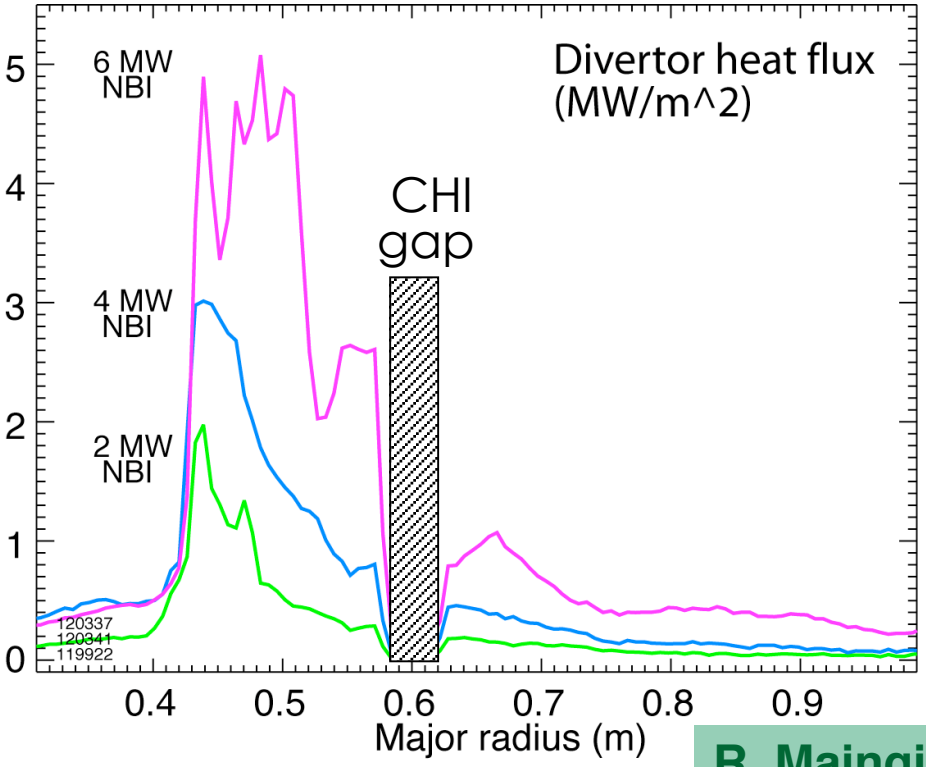
- NSTX Edge Physics Milestone FY2008
  "Study variation and control of SOL heat flux…"

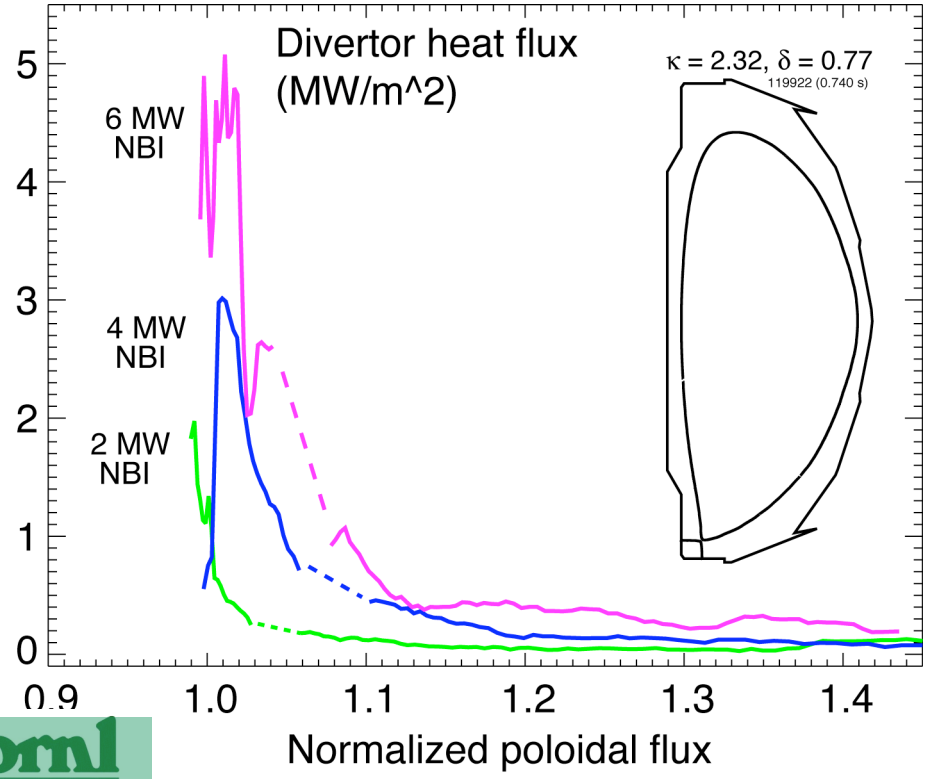
- NSTX high $\kappa$, $\delta$ LSN plasmas (developed in J. Menard's XP) show potential for future ST-CTF:
  - high $\beta_t$, $\beta_n$
  - long pulse, high H89P scaling factor
  - high bootstrap and non-inductive current fractions
  - small or no ELMs

- Test radiative and dissipative divertor techniques for divertor peak heat flux reduction in highly shaped high performance plasmas

- For elongated plasmas upper divertor properties may be important - Study upper divertor particle and heat fluxes (new FY07)

# Divertor heat flux reduction scenario in highly shaped plasmas may be different

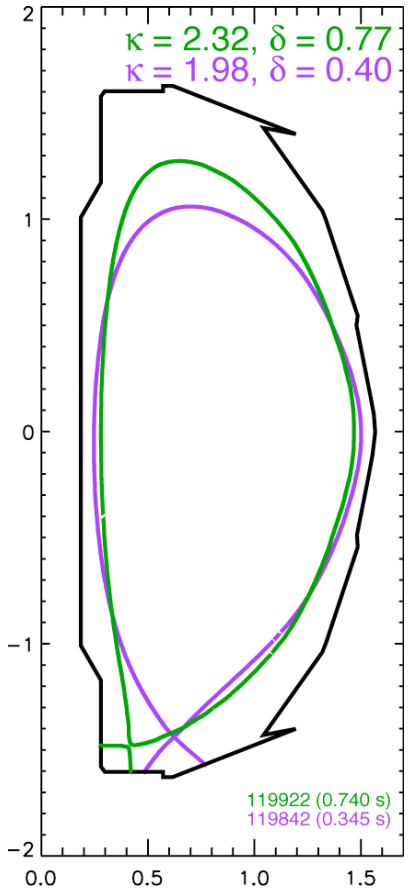


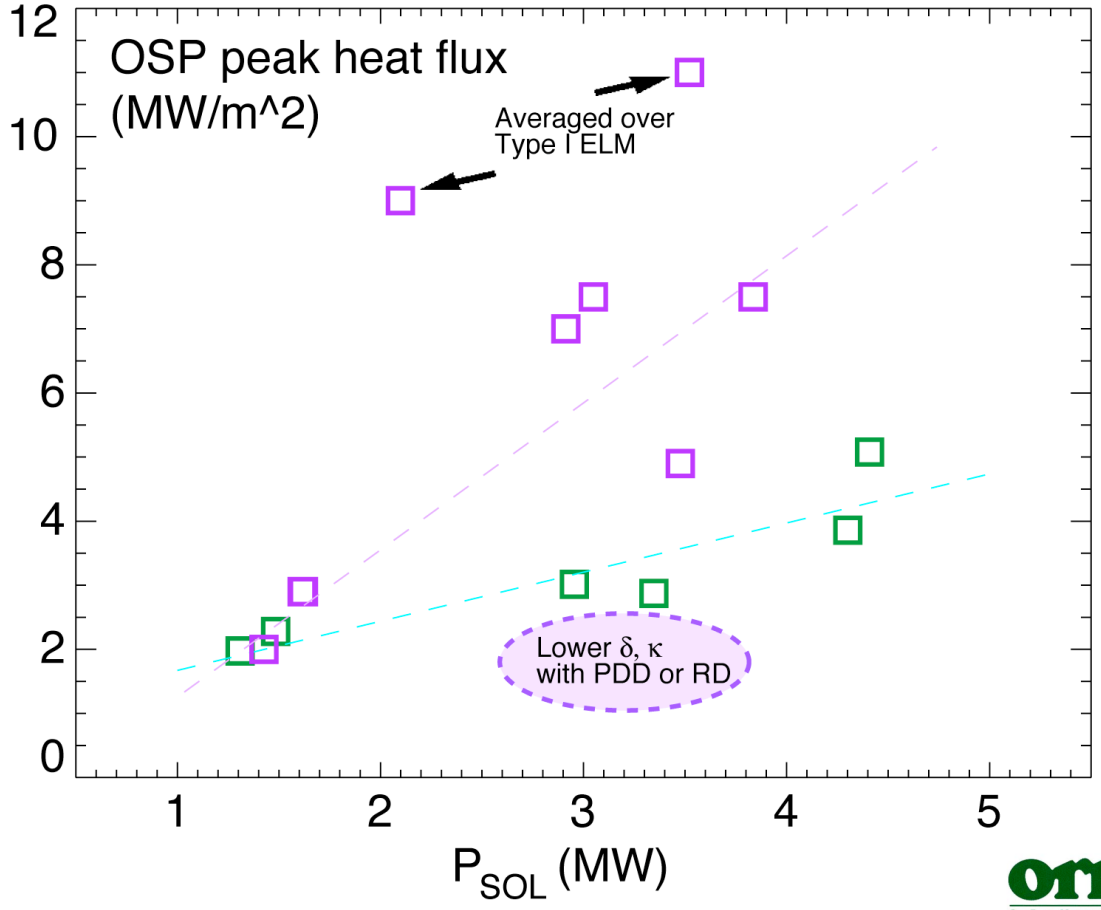




R. Maingi ornl Oak Ridge National Laboratory

- High-performance long-pulse LSN H-mode plasmas (J. Menard)
- Poloidal flux expansion at OSP 20-25
- ISP on vertical target (detached), OSP on horizontal target
- OSP detachment threshold to be investigated (geometry)
- Divertor gas injectors in PFR and OSP region

# More favorable scaling of peak OSP heat flux with input power is obtained in higher κ, δ plasmas




R. Maingi

- Scaling depends on fueling location and gas injection rate
- $P_{SOL}$ is determined from measured and TRANSP-calcualted quantities as

$$P_{SOL} = P_{NBI} + P_{OH} - dW_{MHD}/dt - P_{rad}^{core} - P_{fast\ ion}^{loss}$$

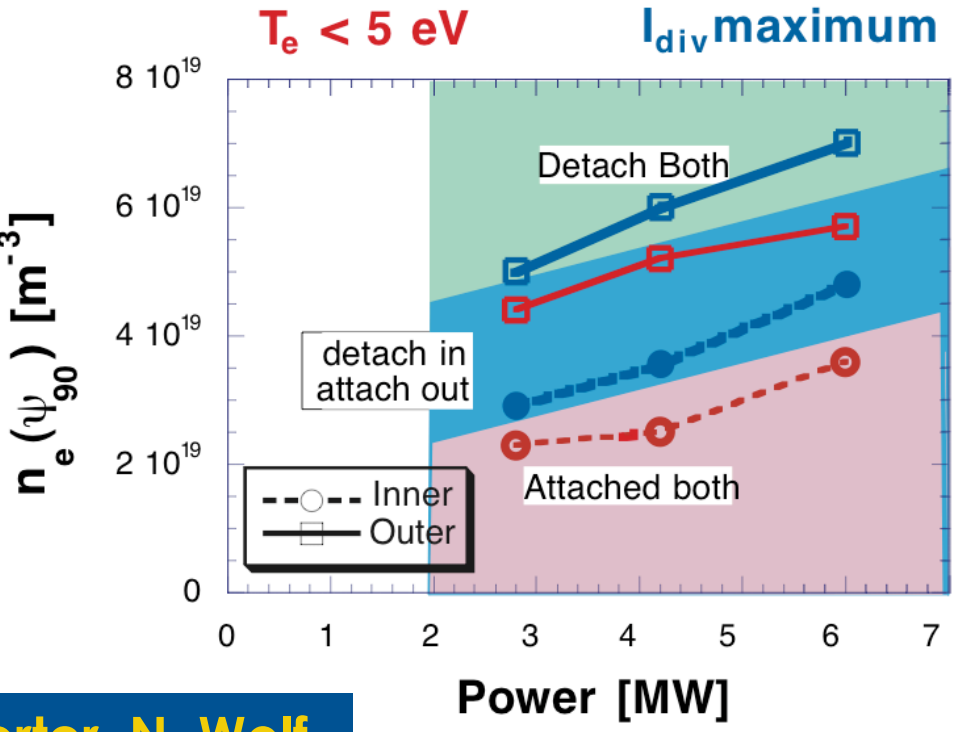
# Publications and collaborations

- Publications
  - Oral talk in NSTX session at APS 2005
  - PSI-17 poster
  - Two JNM papers (2005, 2007)
  - IAEA FEC 2006 individual poster and paper
  - Paper to be submitted to NF (01/2007)

- Collaboration potential
  - Discussed possible collaboration with DIII-D (through LLNL program)
  - Discussed collaboration with J. Myra (Lodestar)
  - Possible collaboration with MAST

# UEDGE modeling guided detachment experiments

- Model divertor conditions *vs* $P_{in}$, $n_{edge}$ with UEDGE to guide experiment
- Generic low $\kappa,\delta$ LSN equilibrium used
- Diffusive transport model
- Impurities (carbon) included
- Outer midplane $n_e$, $T_e$ profiles matched, $D_\alpha$ and IRTV not matched




G. Porter, N. Wolf

Parallel momentum and power balance:

$$\frac{d}{ds}(m_i n v^2 + p_i + p_e) = -m_i(v_i - v_n)S_{i-n} + m_i v S_R$$

$$\frac{d}{ds}((-\kappa T_e^{5/2}\frac{dT_e}{ds}) + n v_{||}(\frac{5}{2}(T_i + T_e) + \frac{1}{2}m_i v_{||}^2 + I_0)) = S_E$$

# Large momentum and power losses are needed for divertor detachment according to 2PM-L

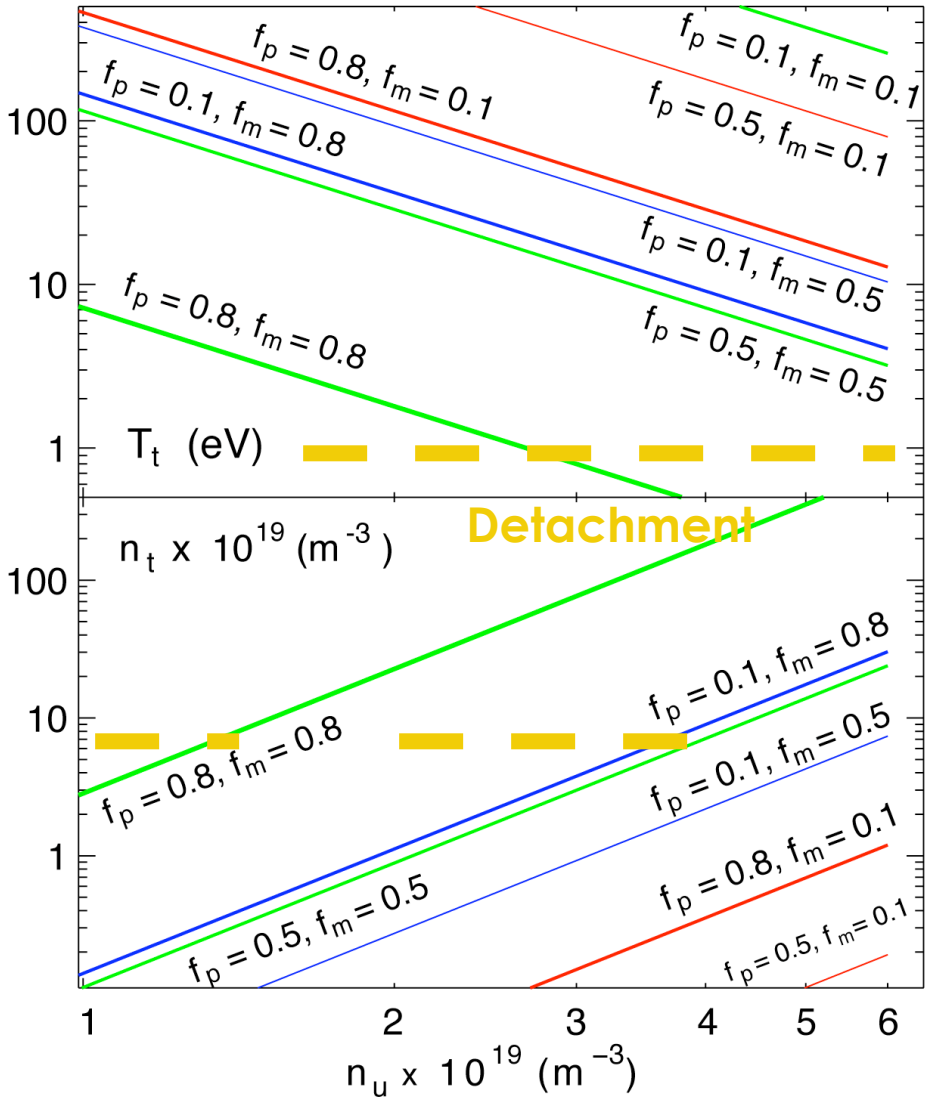
- Two point model with losses
- $f_p$, $f_m$ scanned, $f_{cond}$=0.9
- $n_u$, $q_{||}$, $L_c$ from experiment

$$(1 - f_{power})\, q_{||} = q_t = \gamma\, T_t\, n_t\, c_{St}$$

$$2\, n_t\, T_t = f_{mom}\, n_u\, T_u$$

$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2}\, \frac{f_{cond}\, q_{||}\, L_c}{\kappa_{0e}}$$

$$\Gamma_t \sim \frac{f_{mom}^2\, f_{cond}^{4/7}}{1 - f_{power}}$$




$L_c$ =20 m, $q_{||}$ = 25-30 MW/m$^2$

# NSTX Lower Dome and Branch 5 gas system