Supported by Office of Science

# Divertor heat flux reduction and detachment in CTF-relevant (highly shaped) plasmas


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*Acknowledgements:*

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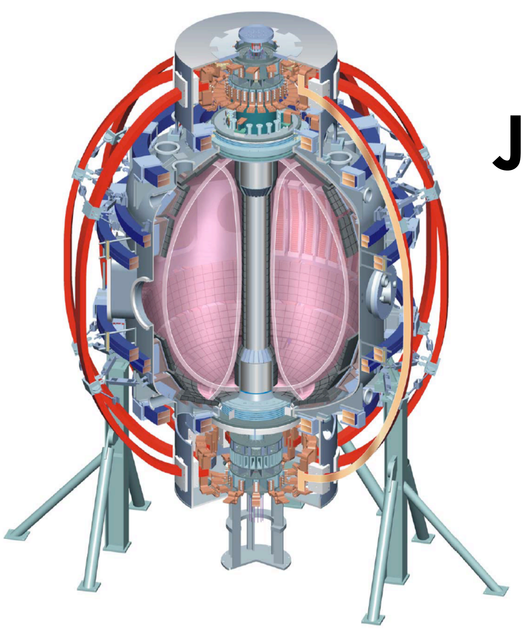


**NSTX Physics Meeting**
**26 February 2007**
**Princeton, NJ**

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

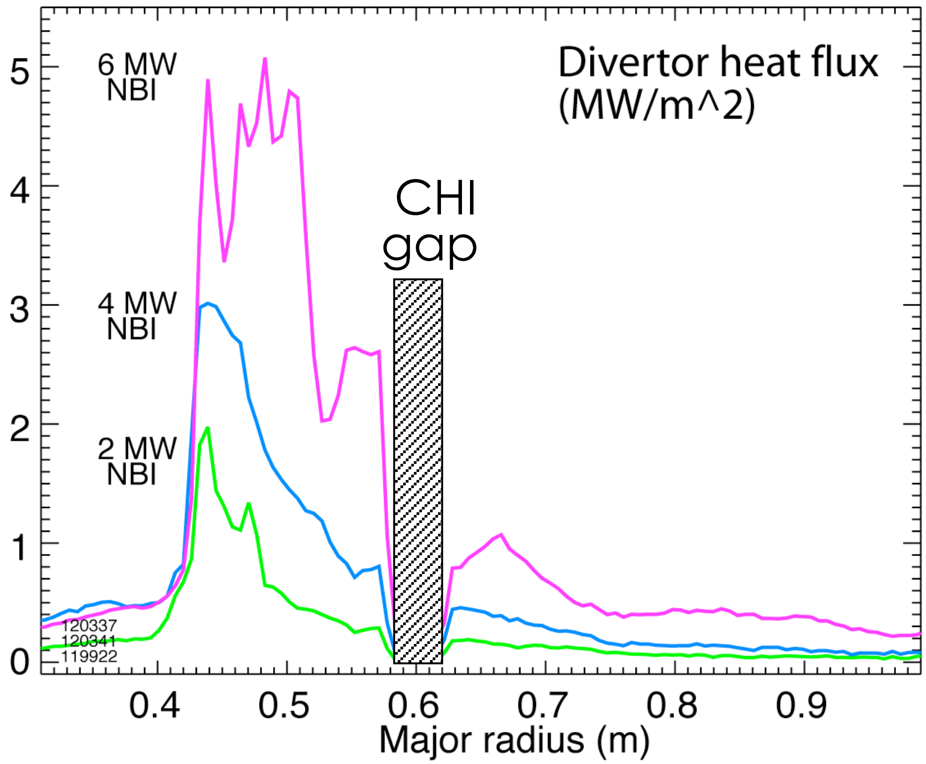
- NSTX Edge Physics Milestone FY2008
  "Study variation and control of SOL heat flux…"

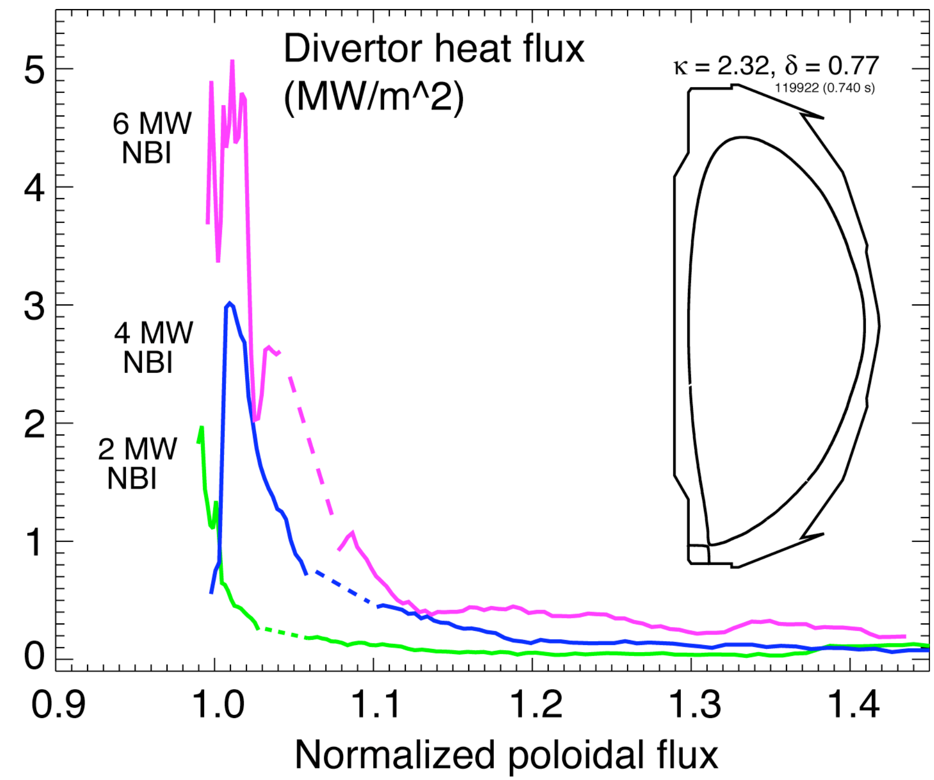
- NSTX high κ, δ LSN plasmas (developed in J. Menard's XP) show potential for future ST-CTF:
  - high $\beta_t$, $\beta_n$
  - long pulse, high H89P scaling factor
  - high bootstrap and non-inductive current fractions
  - small or no ELMs

- 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




- 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

**R. Maingi**

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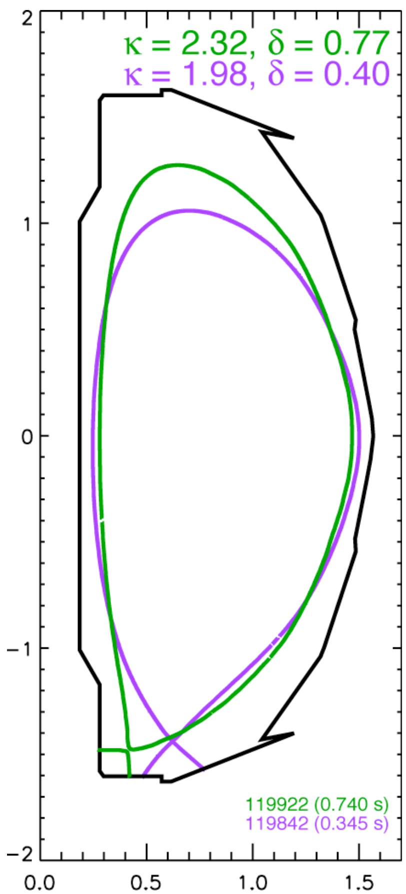
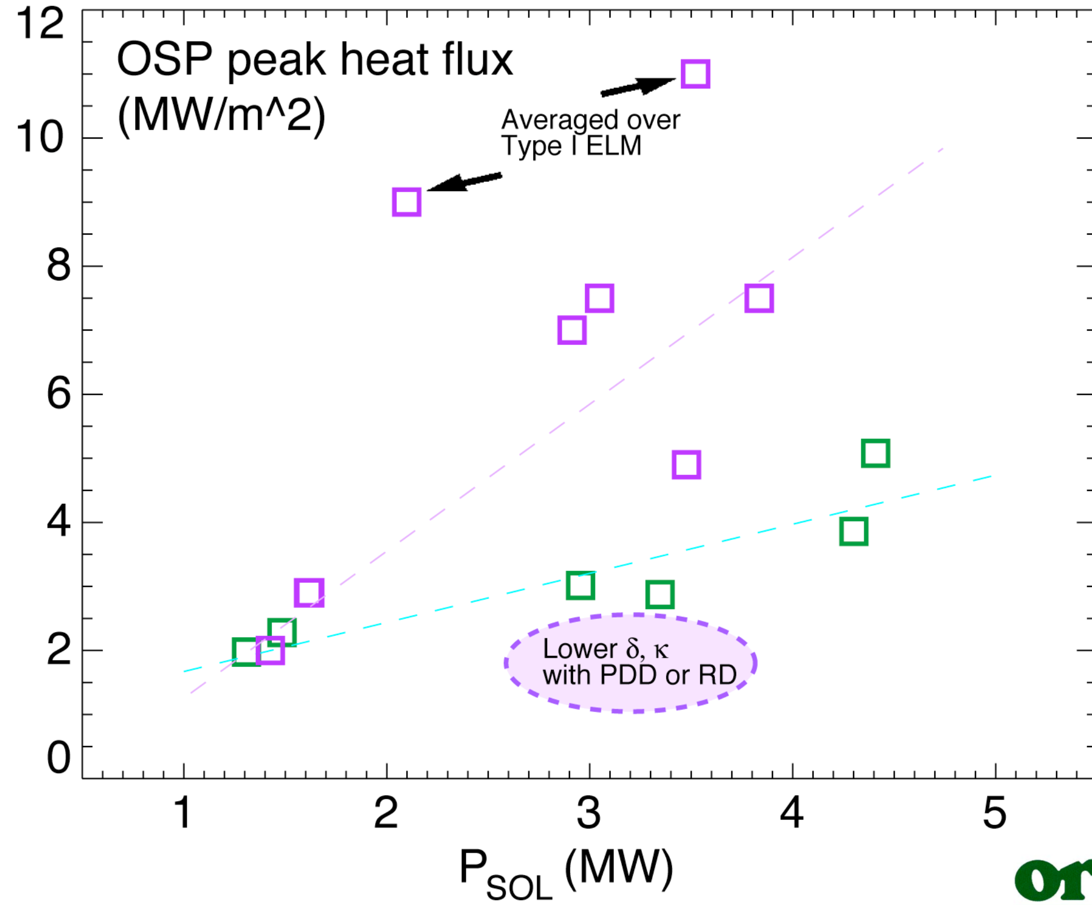
# More favorable scaling of peak OSP heat flux with input power is obtained in higher κ, δ plasmas




R. Maingi

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

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

# Run plan - overview

- **Divertor $D_2$ puffing (~ 0.5-0.7 day)**
  - Target plasma - 4-6 MW H-mode LSN plasma, 0.8 MA, 4.5 kG, $\delta$~0.7-0.8, $\kappa$~2.1-2.3
  - Try 200-400 Torr l / s from LDGIS and 100-160 Torr l /s from Branch 5 injectors

- **(Optional) Extrinsic impurity puffing ($CD_4$ or $N_2$) (~ 0.2-0.5 day)**

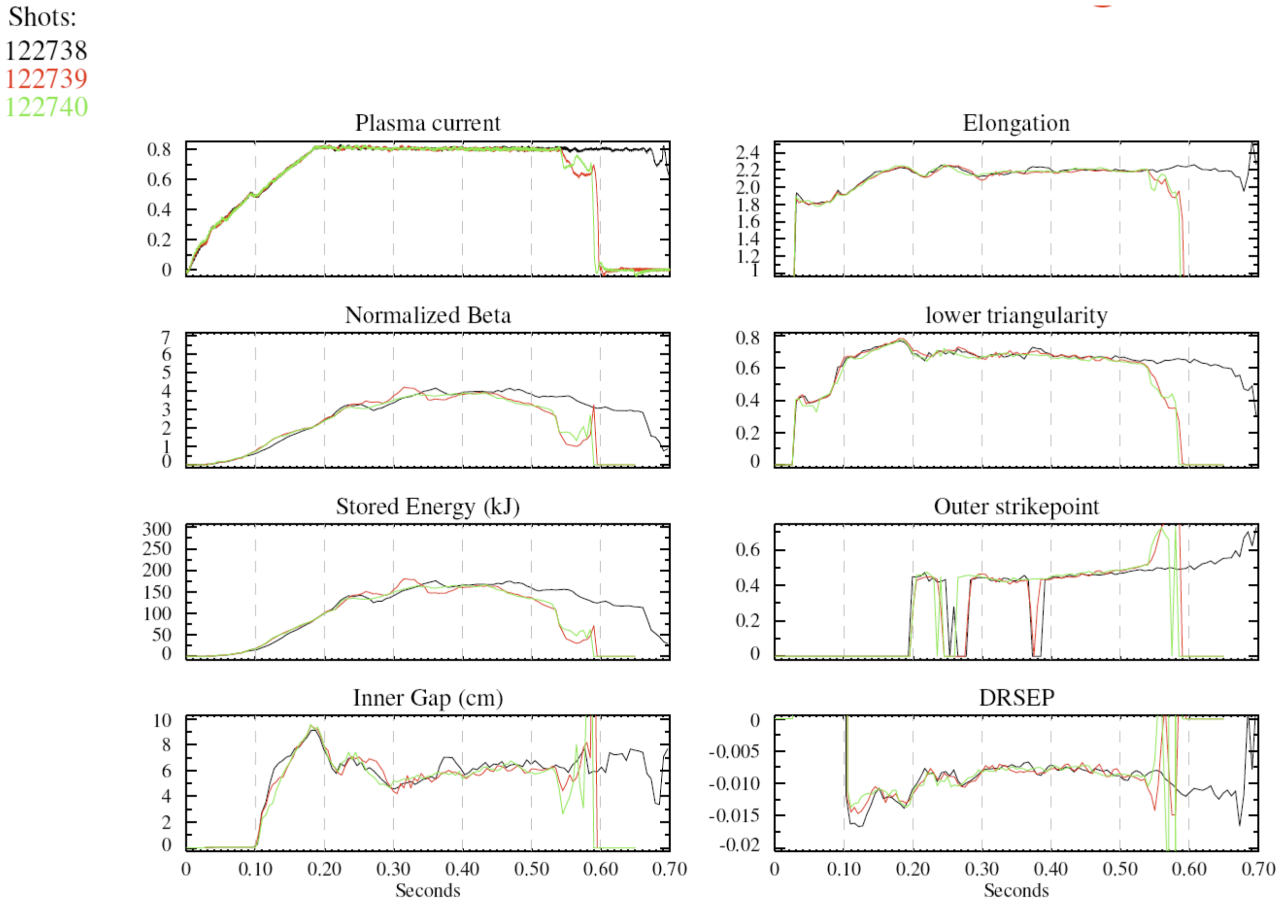
- **Measure divertor heat flux profiles, $D_\alpha$, $D_\gamma$, C III divertor and midplane profiles, rad. power, particle fluxes, edge and divertor $T_e$, $n_e$ for comparison with models**

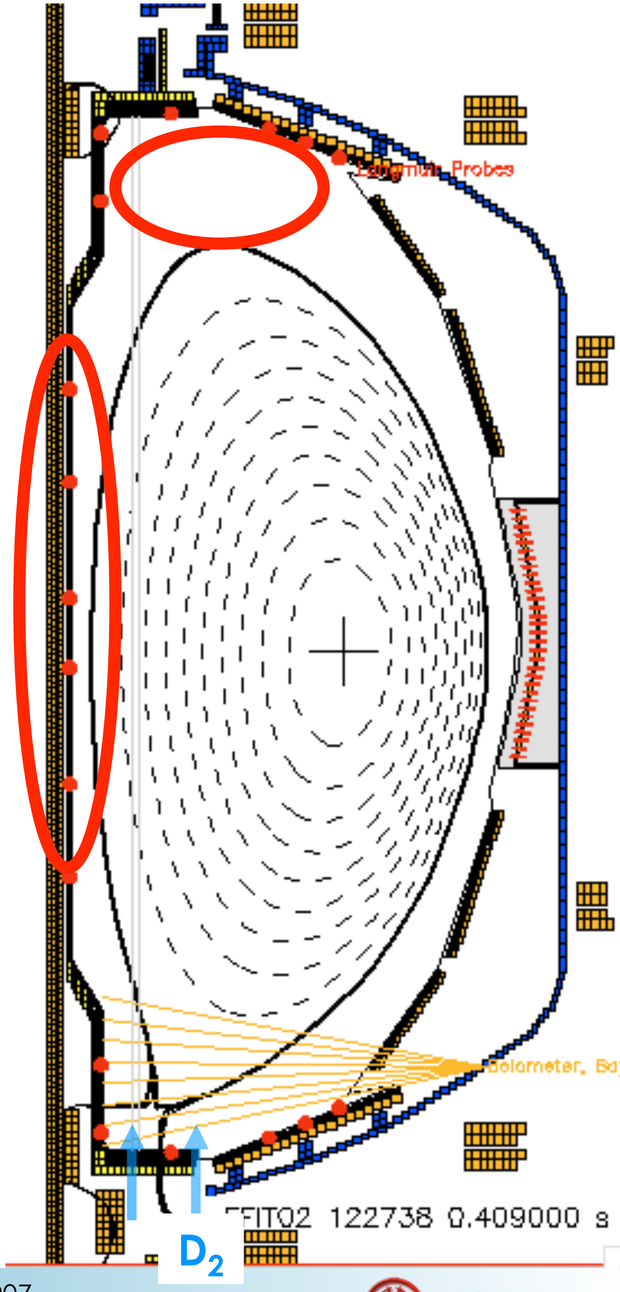
- **If GPI diagnostic and fast cameras are available, test blob radial transport theory**
  - Proposed at NSTX RF FY 07 by J. Myra (Lodestar), also discussed by R. Maqueda (Nova Photonics), J. Boedo (UCSD)
  - Blob rad. velocity increases with resistivity (disconnection from sheath)
  - Disconnection is achieved through X-point cooling or OSP detachment
  - Use UCSD probe, GPI and fast cameras during divertor gas injections

# Summary of 1/2 run day 3 March 2007

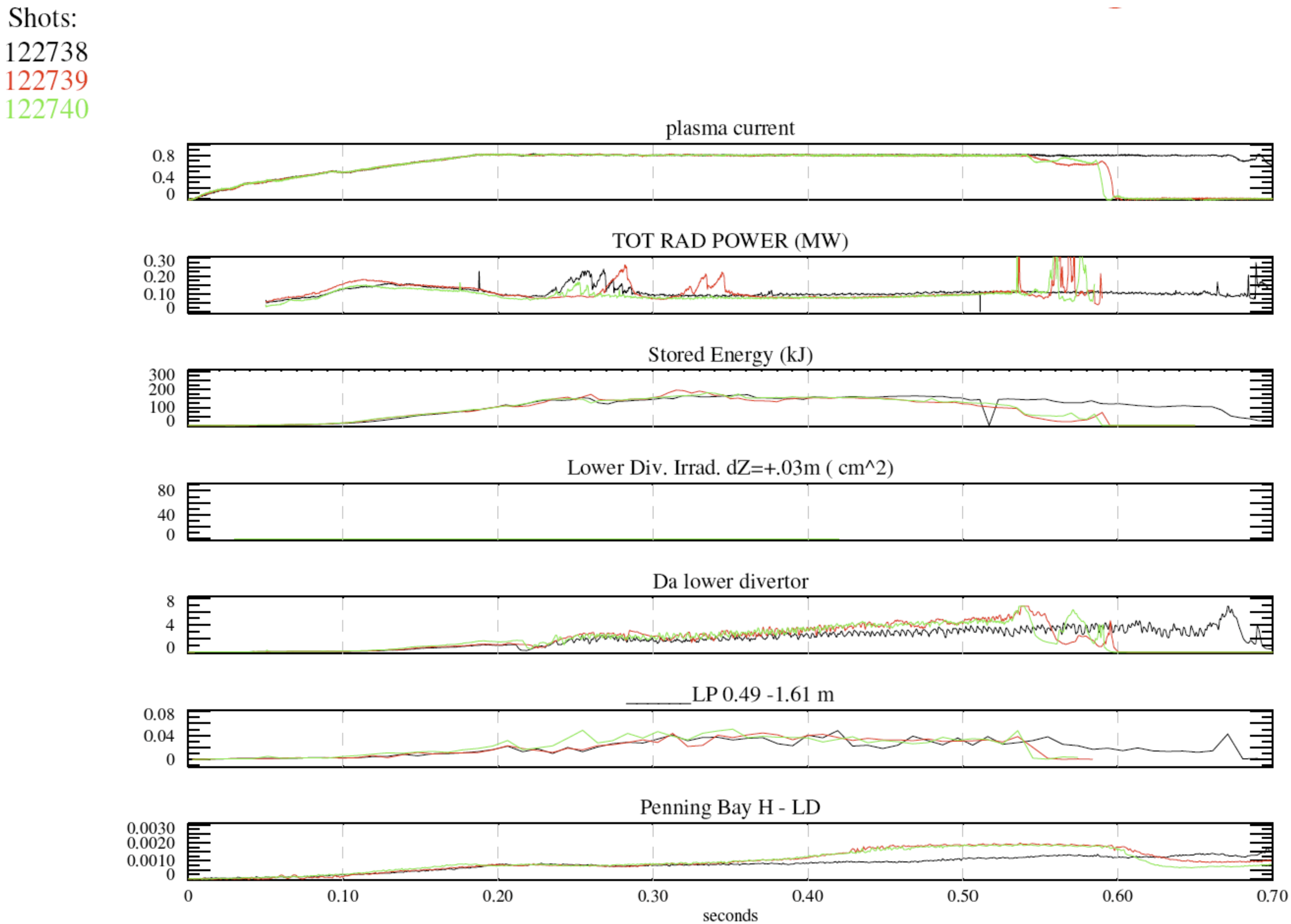
- **Required shape and plasma quality was obtained using rtEFIT control**
- **Obtained good reference 2 NBI and 3 NBI source H-mode shots**
- **Obtained radiative divertor with B5 gas injection with clearly reduced divertor heat flux in 2 NBI source shots**
  - Camera, Langmuir probe and spectroscopy data collected
  - Peak heat flux reduced by 30-40 % (preliminary analysis)
  - Confinement degrded by ~ 10 %, retained H-mode
- **Data in 3 NBI source plasmas is being analyzed**

# rtEFIT control helped achieve and maintain critical plasma shape parameters with high accuracy



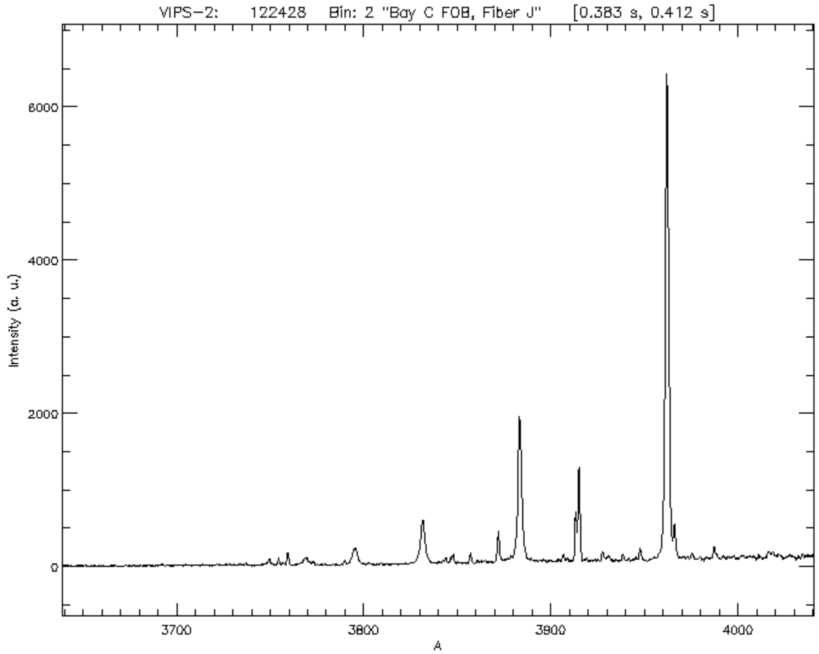
# Radiative divertor conditions were established without significant confinement degradation



# Future directions and plans

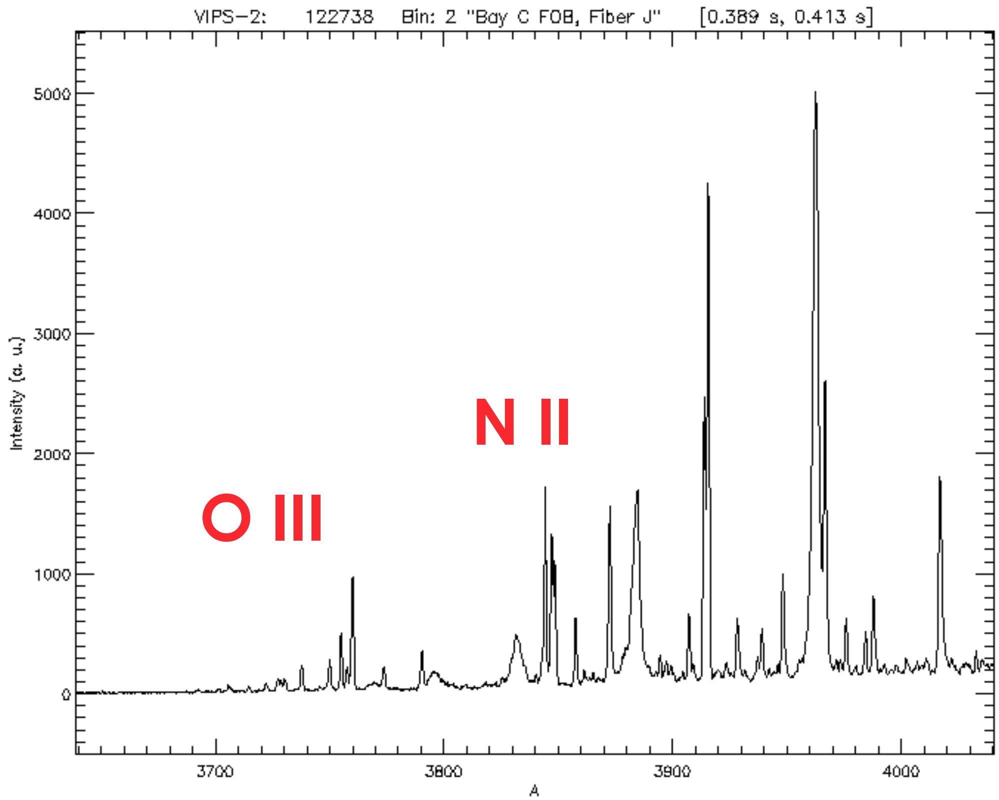
- **Analysis:**
  - IR heat flux data
  - Dα, Dγ, C II, CIII divertor profiles for signs of recombination and detachment
  - Divertor Langmuir probe $I_{sat}$, $T_e$, $n_e$
  - VIPS divertor spectra - $T_e$, $n_e$, signs of recombination
- **Obtain data in 0.8 MA 3 NBI source plasmas**
- **Obtain data in 1.0-1.2 MA 3 NBI source plasmas - highest divertor heat flux**
- **Try impurity ($N_2$ or $CD_4$) gas puffing**

# VIPS spectra indicate traces of oxygen and nitrogen in plasma




20 February 2007

3 March 2007



# Back-up slides

# Divertor peak heat flux reduced by 2-5 with radiative/dissipative divertor in lower κ,δ plasmas

- Completed low δ,κ part in 2006
- Multi-institutional experiment - LLNL, ORNL, PPPL, U Washington, UCSD
- C. J. Lasnier (LLNL staff at DIII-D) participated in 2005 experiment

- NSTX results to date (4 MW NBI lower δ,κ H-mode plasma)
  - ☑ OSP does not detach at high densities ($n_e \sim n_G$) as a result of short L and open divertor geometry. ISP detaches at low $n_e$, $P_{in}$
  - ☑ Midplane neon puffing produces radiative mantle
  - ☑ Obtained OSP partial detachment with high-rate $D_2$ puffing in ISP region
    - ✓ Peak OSP heat flux reduced by 2-5
    - ✓ Core confinement degrades within 2-5 $\tau_E$
    - ✓ H-L transition within 20-50 ms (too much gas)
    - ✓ X-point MARFE forms quickly
  - ☑ Obtained radiative divertor with moderate $D_2$ puffing in PFR or ISP region
    - ✓ Peak OSP heat flux reduced by 2-5
    - ✓ Good core confinement (1.6 H89P), H-mode
    - ✓ Outer SOL in high recycling regime
    - ✓ X-point MARFE eventually forms as well
    - ✓ Promising scenario for future experiment

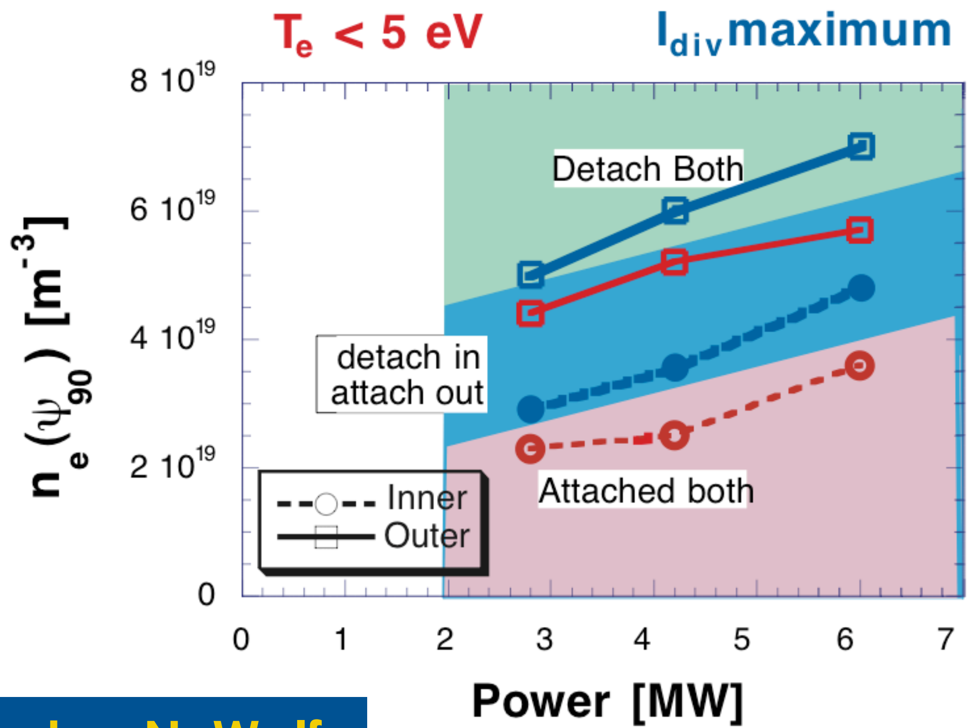
# Publications and collaborations

- 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 κ,δ 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

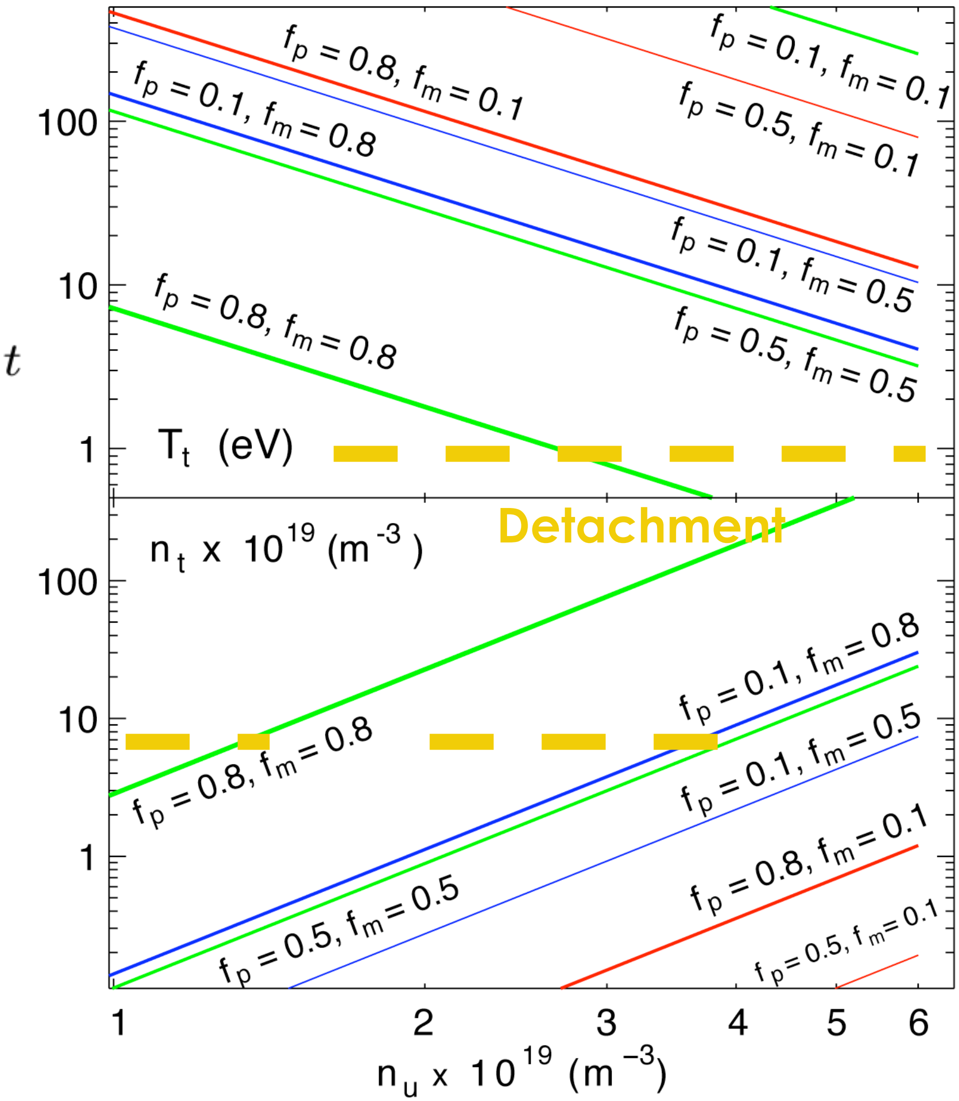
$$(1 - f_{power})\, q_{||} = q_t = \gamma\, T_t\, n_t\, c_{St}$$

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

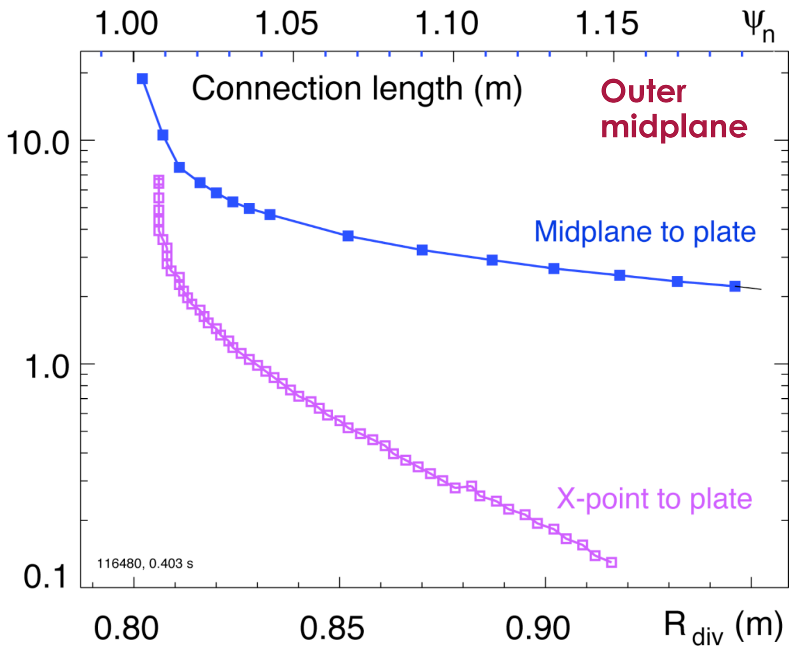
$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2}\, \frac{f_{cond}\, q_{||}\, L_c}{\kappa_{0e}}$$

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

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

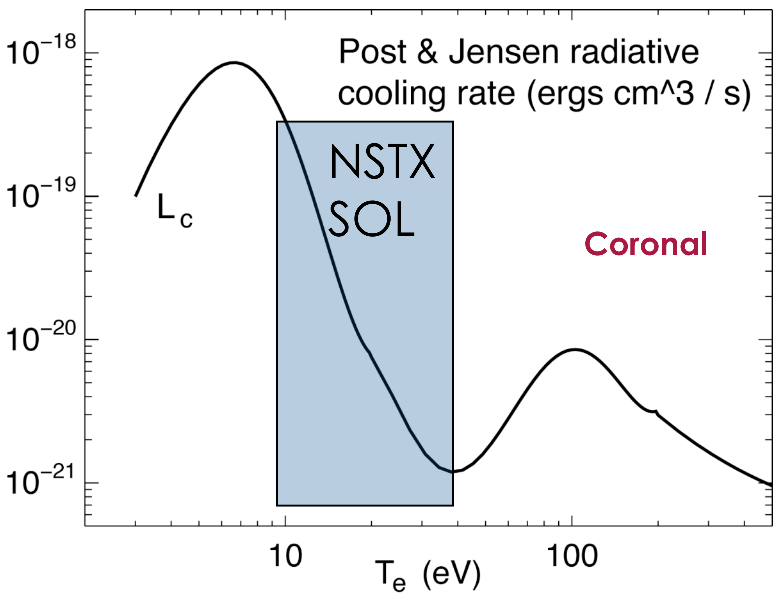


# Why is it difficult to obtain OSP detachment?




- Connection length decreases to very short values within radial distance of 1-3 cm (both midplane to plate and X-point to plate)

- SOL temperature 10-40 eV (rather low)
- Weak $dT_e/ds_{||}$ in high-recycling outer SOL
- Carbon cooling rate max at $T_e$ < 10 eV

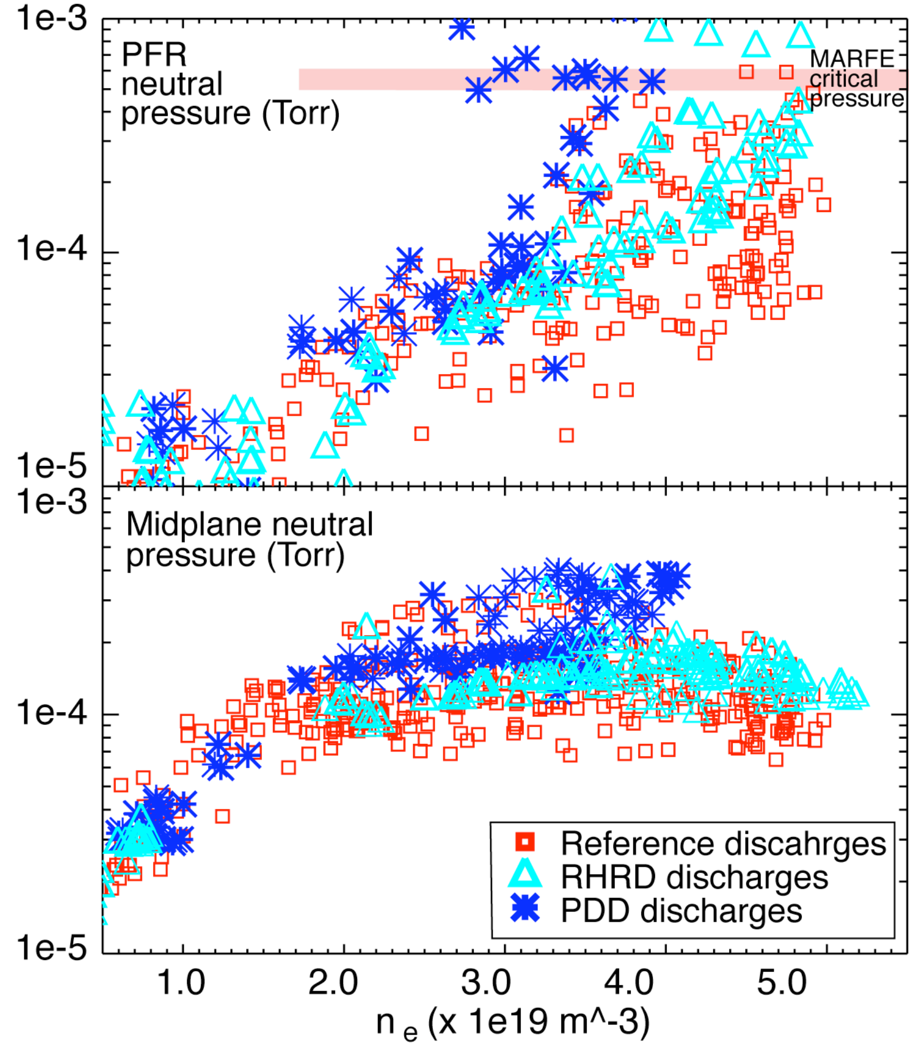



- Recombination time:
  $\tau_{rec} = 1./(n_e R_{rec}) \sim 1\text{–}10$ ms at $T_e$ =1.3 eV
  Ion divertor residence time:
  $\tau_{ion} = L_d/v_{ion} \sim 0.8$ ms (with $v_{ion} \sim 10^4$ m/s)

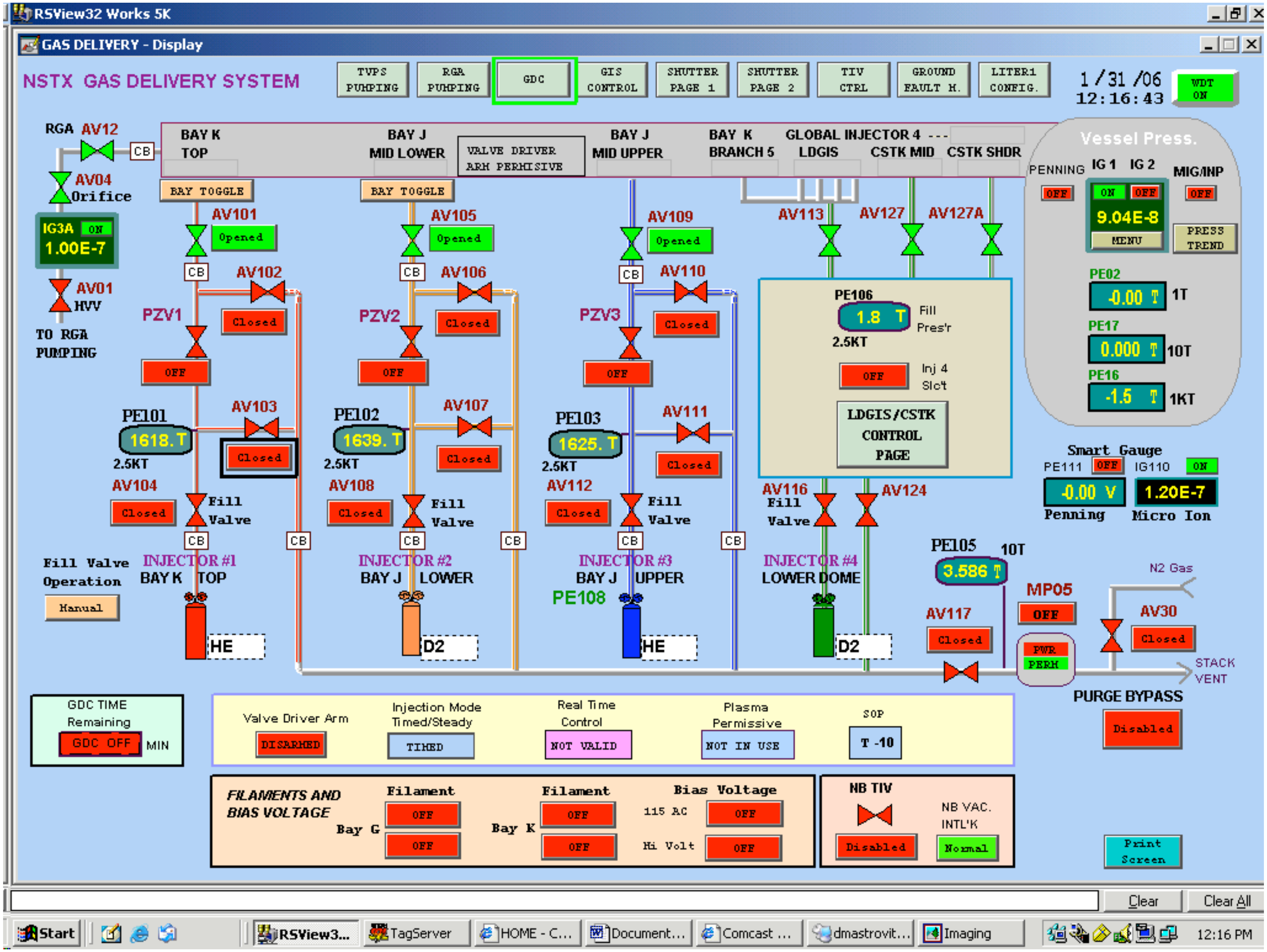
- Open divertor geometry - high detachment threshold is expected
- Neutral compression ratio is 5-10 (low)

# Observed midplane and PFR pressure trends are due to open divertor geometry

- In reference discharges, $n_u$ independent of $P_{mp}$, but a strong linear function of $P_{PFR}$
- X-point MARFE critical PFR pressure is 0.5-0.6 mTorr
- Reference discharges never reach PFR critical pressure
- PDD discharges reach MARFE onset PFR pressure faster than RD discharges
- $P_{mp}$ similar in ref. and RD discharges
- $P_{mp}$ higher in PDD discharges (stronger gas puffing)



# NSTX Gas system



# NSTX Lower Dome and Branch 5 gas system