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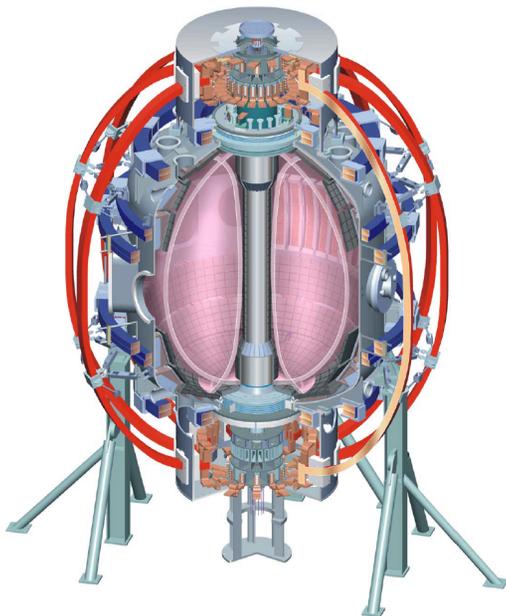
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Divertor heat flux reduction and detachment in CTF-relevant (highly shaped) plasmas

**V. A. Soukhanovskii
and the NSTX Team**

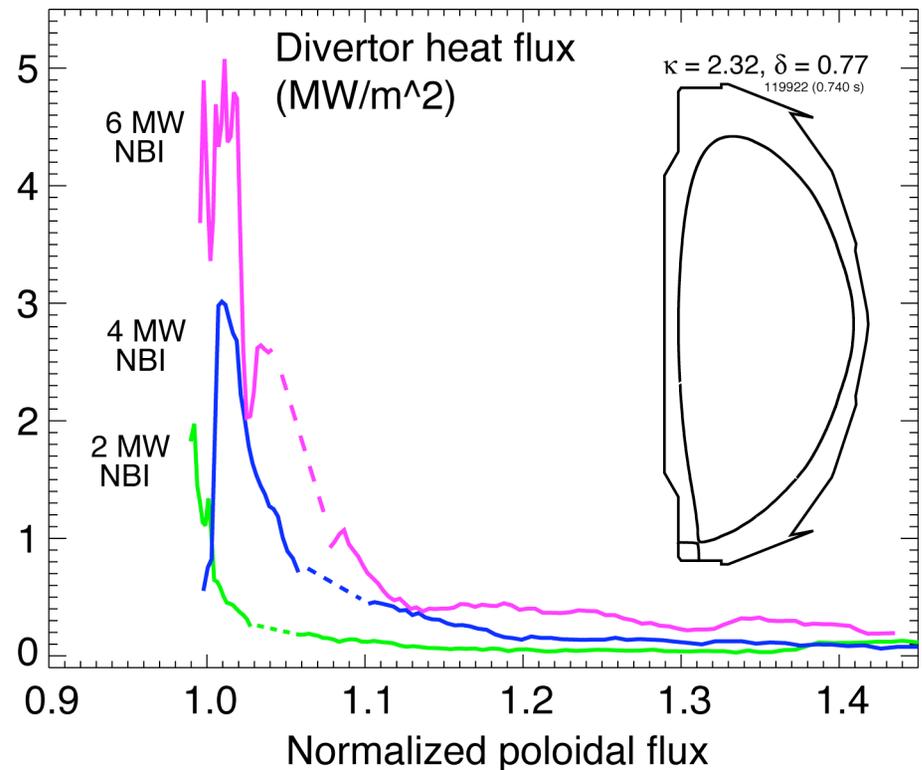
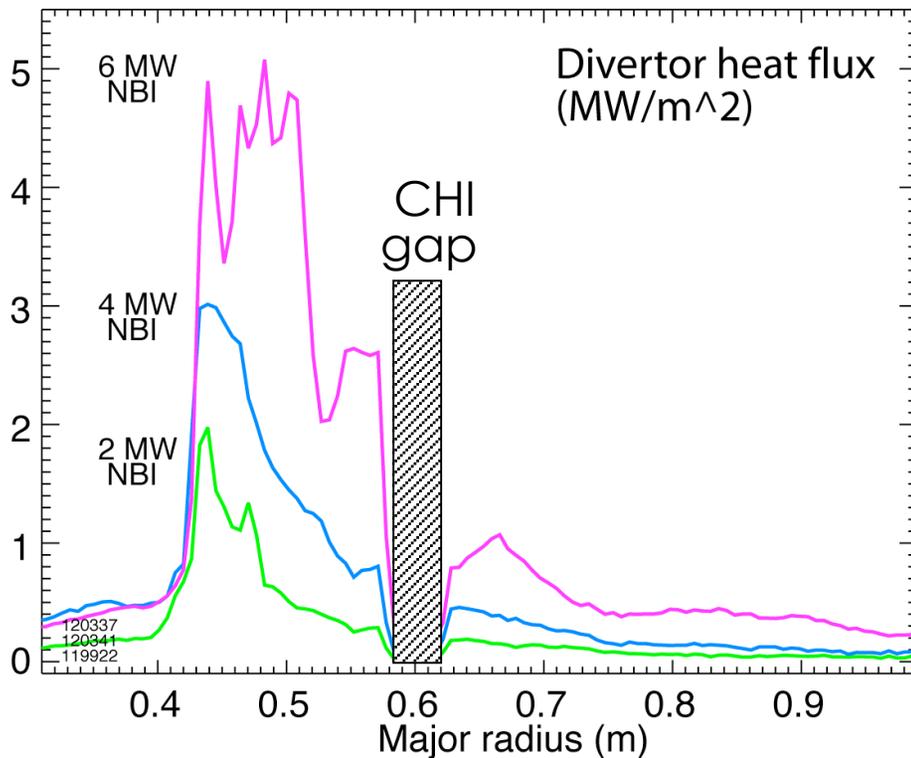
**NSTX Physics Meeting
26 February 2007
Princeton, NJ**



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

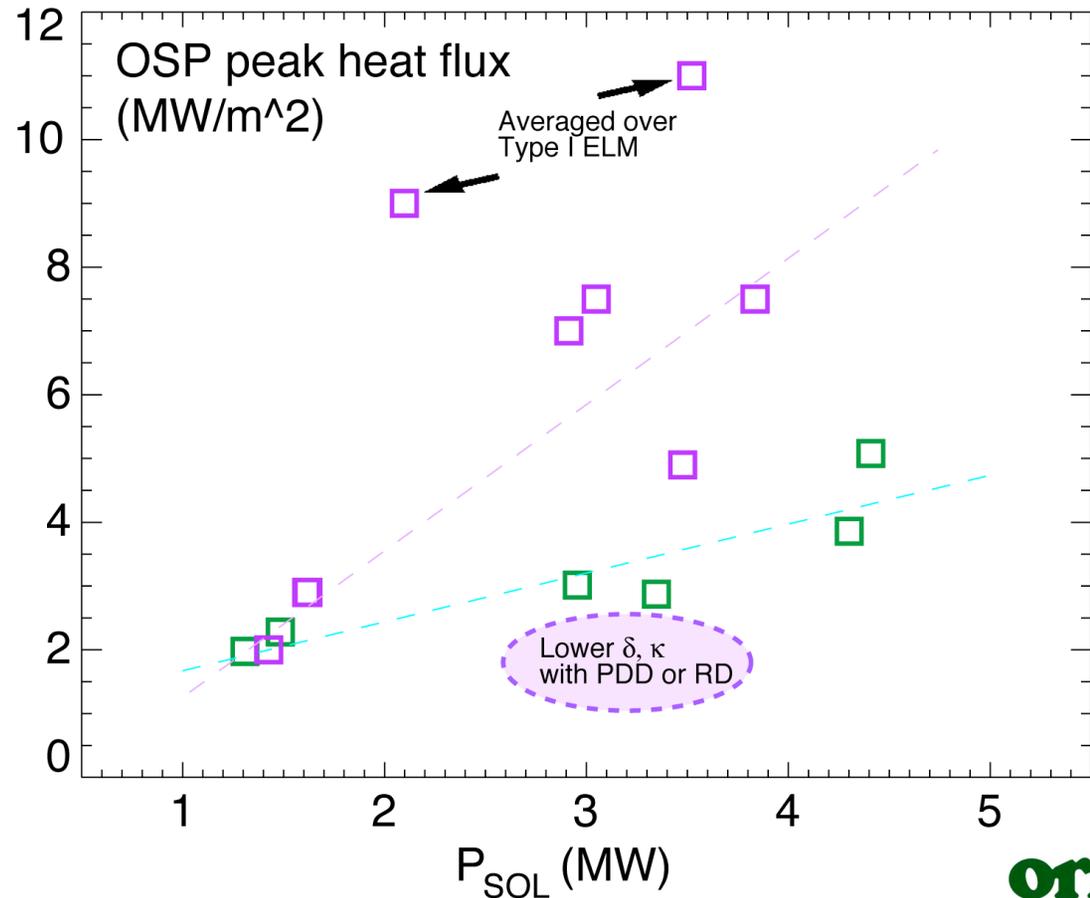
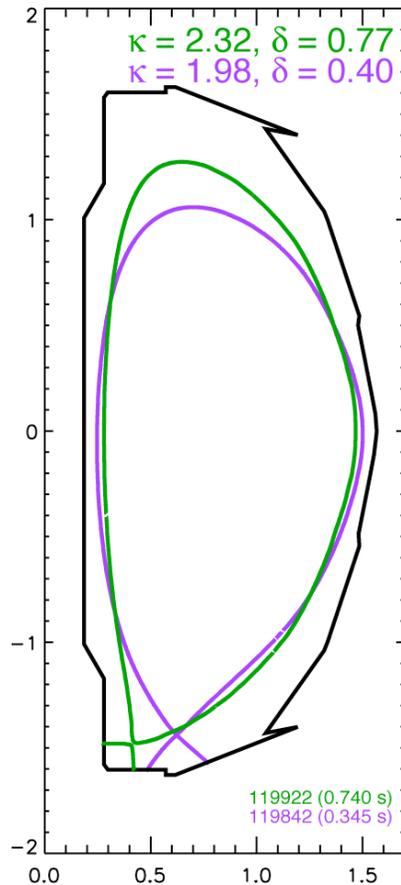
Divertor heat flux reduction scenario in highly shaped plasmas may be different



- 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
oml
OAK RIDGE NATIONAL LABORATORY

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



ornl
OAK RIDGE NATIONAL LABORATORY
R. Maingi

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

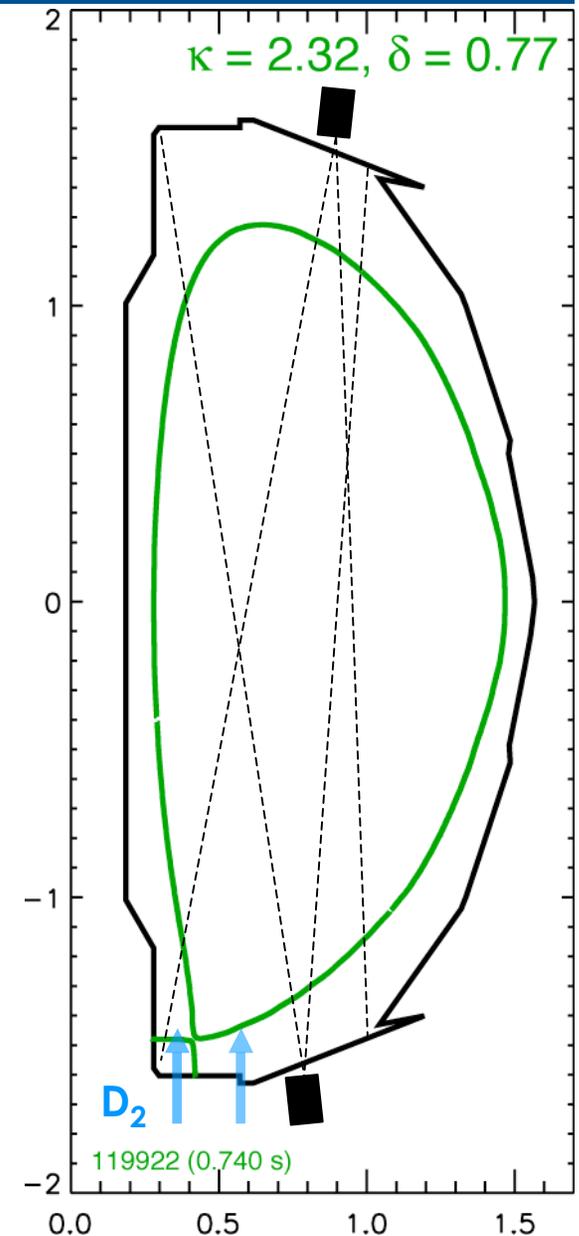
$$P_{SOL} = P_{NBI} + P_{OH} - dW_{MHD}/dt - P_{rad}^{core} - P_{fast\ ion}^{loss}$$

Run plan - overview

- **Divertor D₂ puffing (~ 0.5-0.7 day)**
 - Target plasma - 4-6 MW H-mode LSN plasma, 0.7-0.8 MA, 4.5 kG, $\delta \sim 0.7-0.8$, $\kappa \sim 2.3$
 - Try 200-400 Torr I / s from LDGIS and 100-160 Torr I /s from Branch 5 injectors
- **(Optional) Extrinsic impurity puffing (CD₄ or N₂) (~ 0.2-0.5 day)**
- **Measure divertor heat flux profiles, D_α, D_γ, 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

Results of 1/2 run day 20 February 2007

- **Required shape and plasma quality could not be obtained**
 - Target plasma - 4 MW H-mode LSN plasma, 0.8 MA, 4.5 kG, $\delta \sim 0.7-0.8$, $\kappa \sim 2.3$
 - Machine conditions were adequate but plasma responded differently to the template shot coil currents (I_i different)
 - Inner gap, D_{rsep} , outer SP drifted too much
- **Diagnostics did not cooperate**
 - Lower divertor infrared camera did not work
 - Swapped two cameras during a controlled access - worked
- **Ran 3 shots with gas puffs - measured divertor heat flux profiles, $D_{\alpha'}$, D_{γ} divertor profiles, rad. power**



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 τ_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

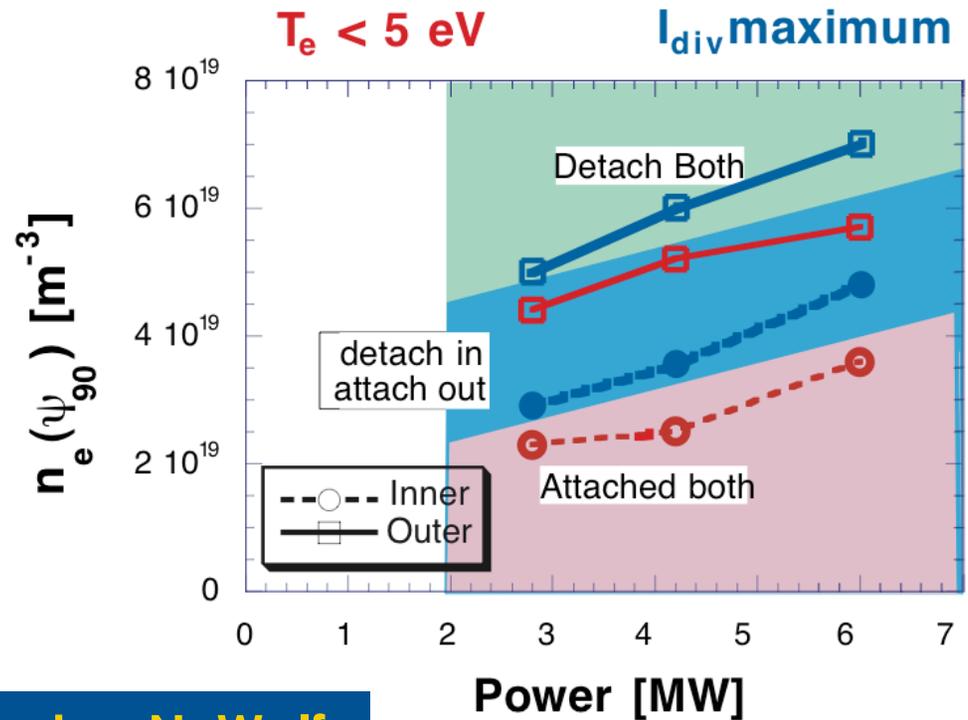
Publications and collaborations

- 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_α and IRTV not matched



 G. Porter, N. Wolf

Parallel momentum and power balance:

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

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

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

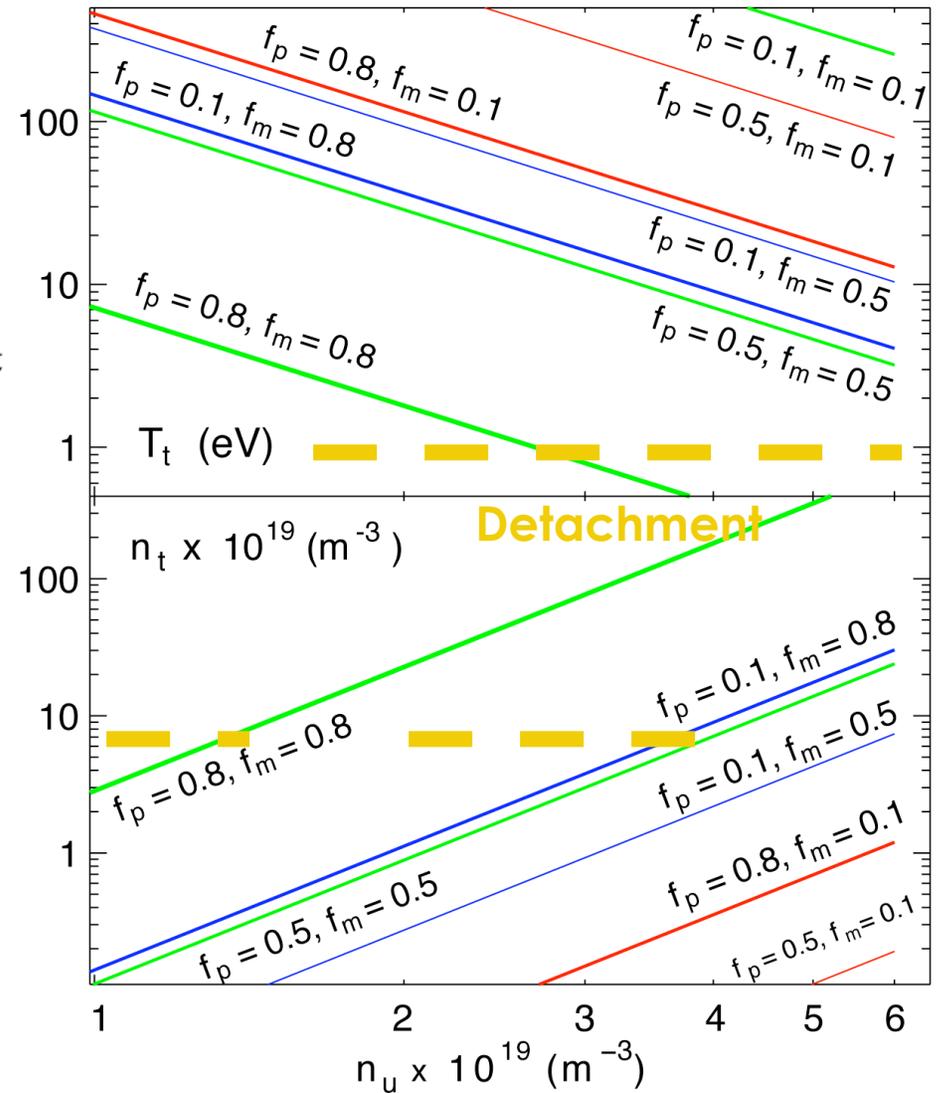
$$(1 - f_{power}) q_{||} = q_t = \gamma T_t n_t c S t$$

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

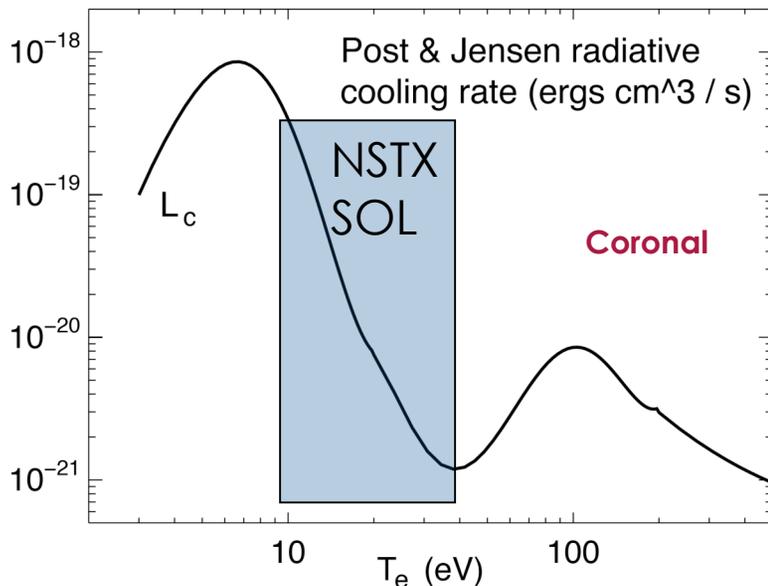
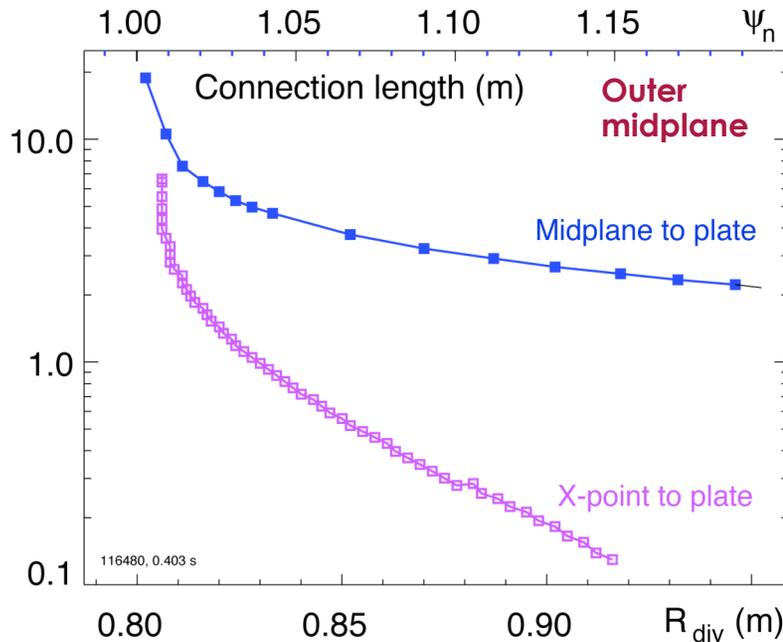
$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2} \frac{f_{cond} q_{||} L_c}{\kappa_{0e}}$$

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

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



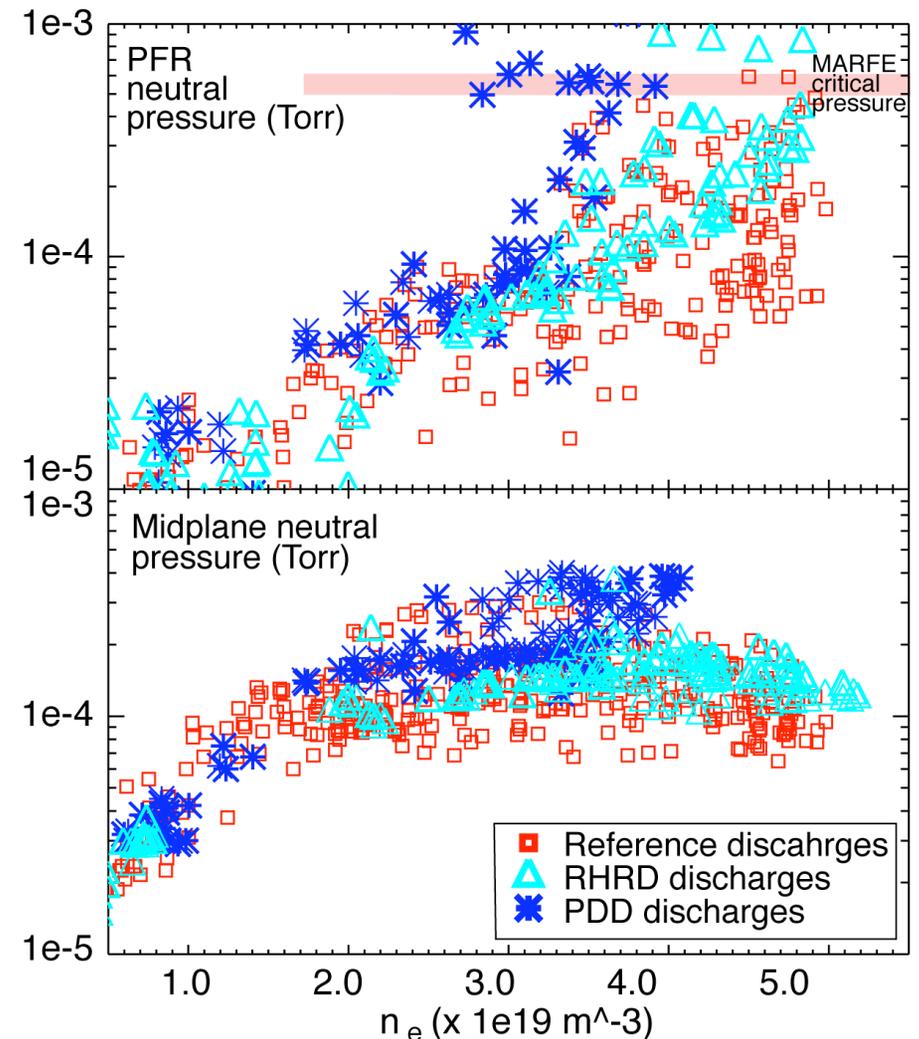
Why is it difficult to obtain OSP detachment?



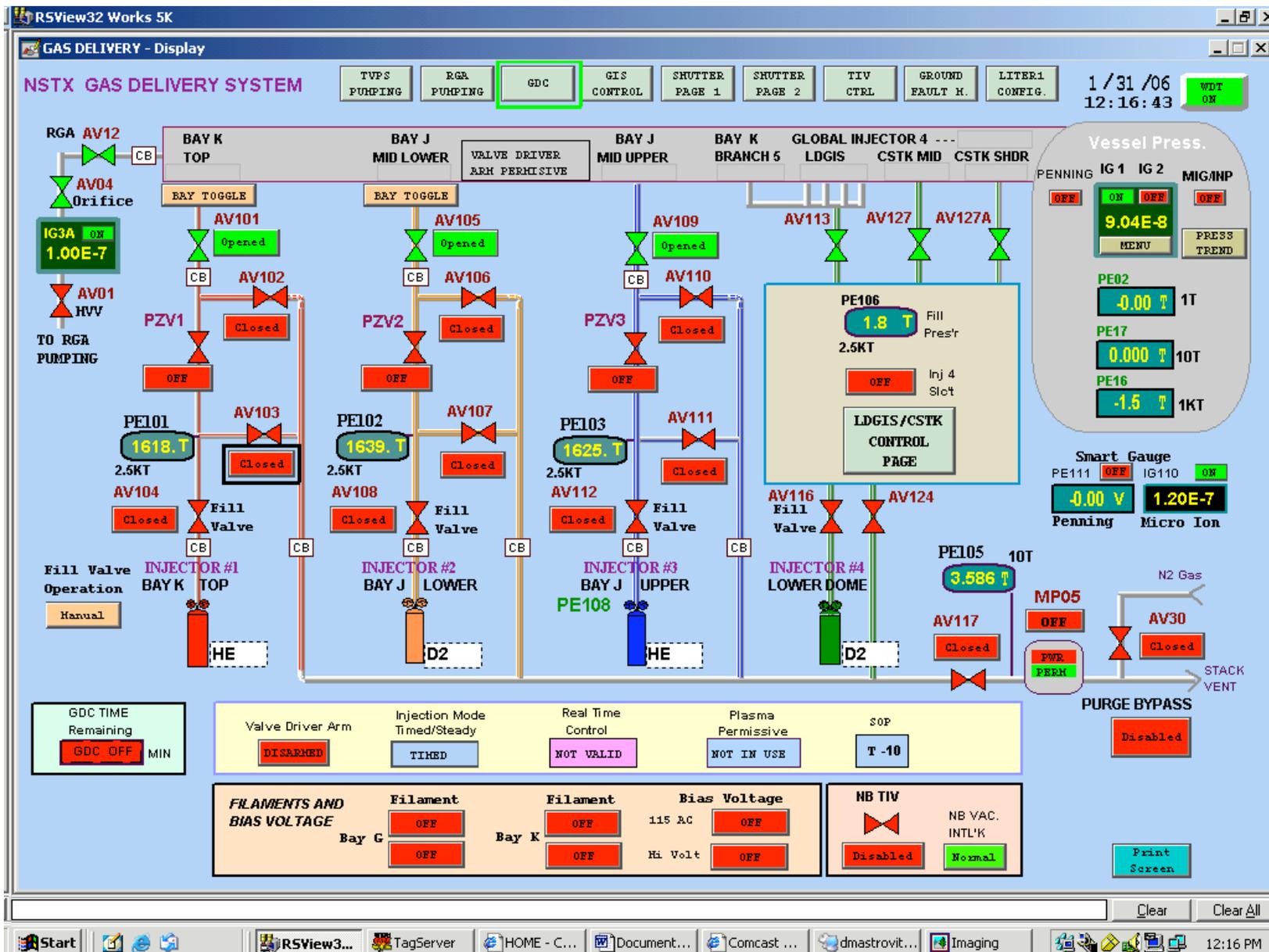
- Connection length decreases to very short values within radial distance of 1-3 cm (both midplane to plate and X-point to plate)
- SOL temperature 10-40 eV (rather low)
- Weak dT_e/ds_{\parallel} in high-recycling outer SOL
- Carbon cooling rate max at $T_e < 10$ eV
- Recombination time:
 $\tau_{rec} = 1./(n_e R_{rec}) \sim 1-10$ 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

LOWER DOME / CSTK GAS INJECTION

TVPS PUMPING
 RGA PUMPING
 GAS DELIVERY
 GIS CONTROL
 GDC
 SHUTTER PAGE 1
 LITER1 CONFIG.
 1 / 31 / 06
 12:19:52
 WDT ON

OPERATION

Injector 4
 OFF

Fill Select
 BRANCH 5

Mode
 NORM

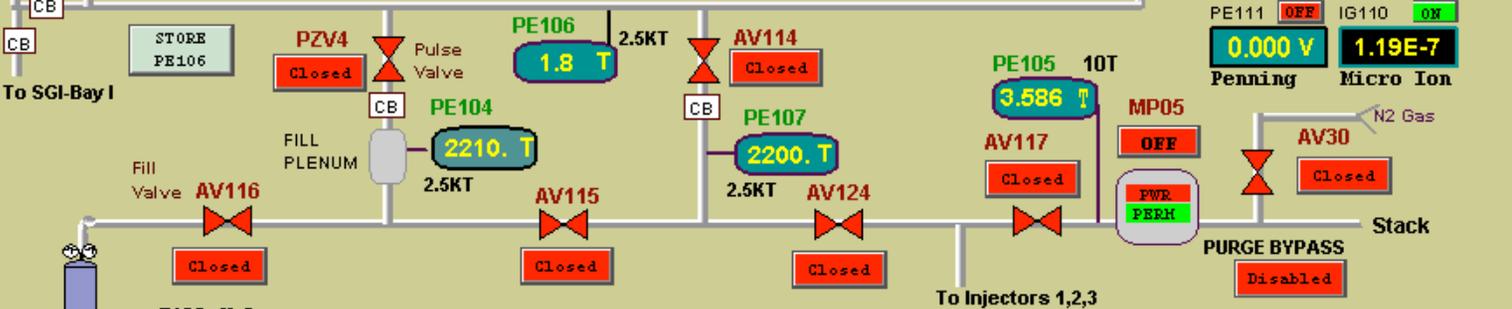
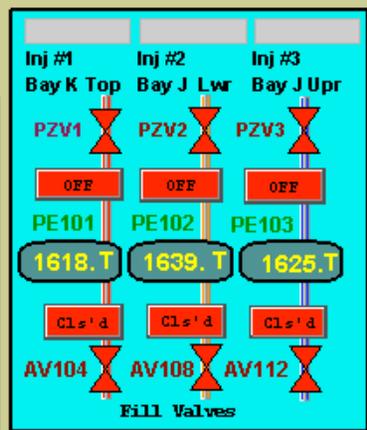
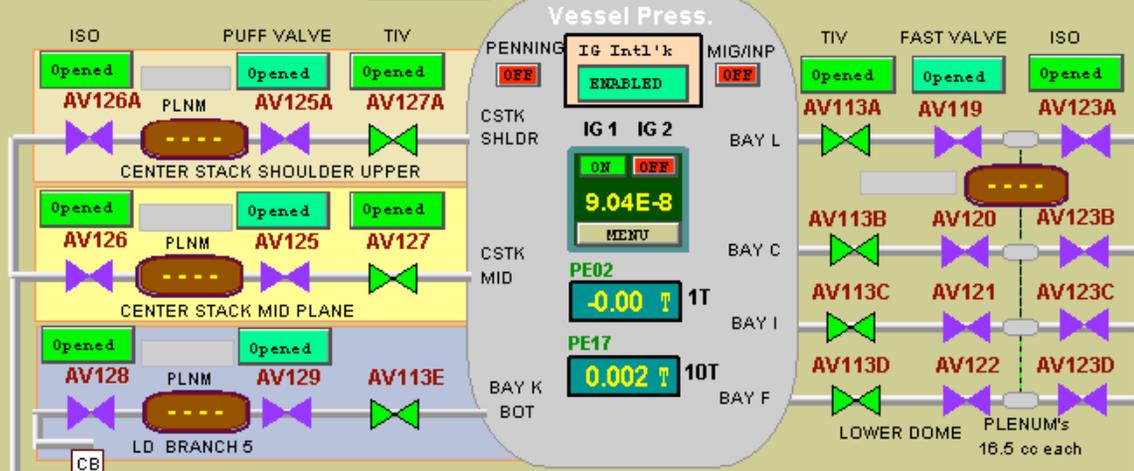
PUFF OFF

PE106 Fill Setpoint
 000 LCL
 1400 T
 PZV4 VOLT 90 V

Plenum Fill

Process Stat
 READY to FILL

GDC TIME Remaining
 MIN



Valve Driver Arm <input type="button" value="DISABLED"/>	Injection Mode Timed/Steady <input type="button" value="TIMED"/>	Real Time Control <input type="button" value="NOT VALID"/>	Plasma Permissive <input type="button" value="NOT IN USE"/>	SOP <input type="button" value="T -10"/>	CHI Power Supply PE104 >750T PE107 >750T PE106 <100T <input type="button" value="GAS PERMISSIVE"/>
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FILAMENTS AND BIAS VOLTAGE	Filament	Filament	Bias Voltage
Bay G	<input type="button" value="OFF"/>	Bay K	115 AC <input type="button" value="OFF"/>
	<input type="button" value="OFF"/>		Hi Volt <input type="button" value="OFF"/>

NB TIV
 NB VAC. INT'L'K

Put RGA in GDC Configuration

RGA orifice RGA
 RUV valve TIV