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

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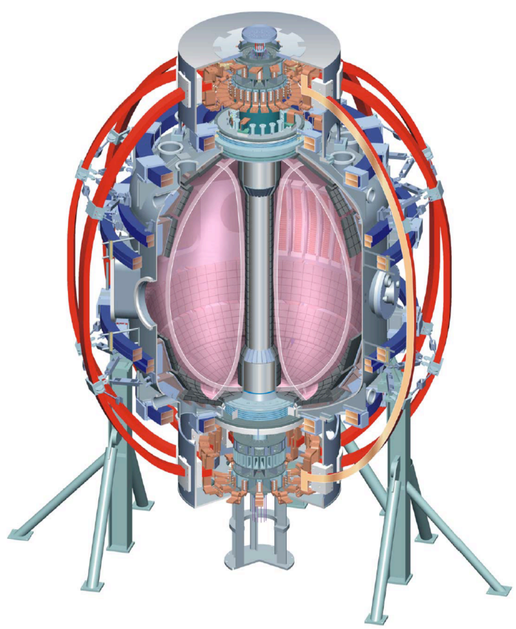
and the NSTX Team



NSTX Team Review
8 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

- Study lower divertor geometry effects on particle and heat fluxes
- Study upper divertor properties on particle and heat fluxes (new FY07)

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

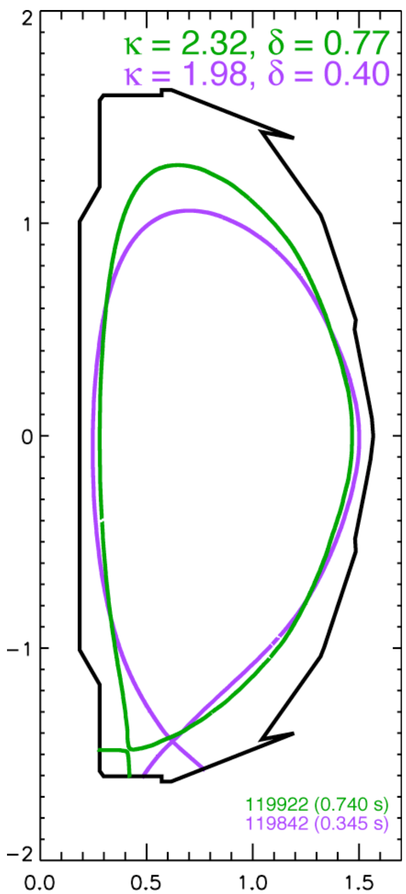
- NSTX results to date (4 MW NBI lower δ,κ H-mode plasma)
  - ☑ OSP does not detach at high densities ($n_e \sim n_G$) as a result of short L and open divertor geometry. ISP detaches at low n_e, P_{in}
  - ☑ Midplane neon puffing produces radiative mantle
  - ☑ Obtained OSP partial detachment with high-rate 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

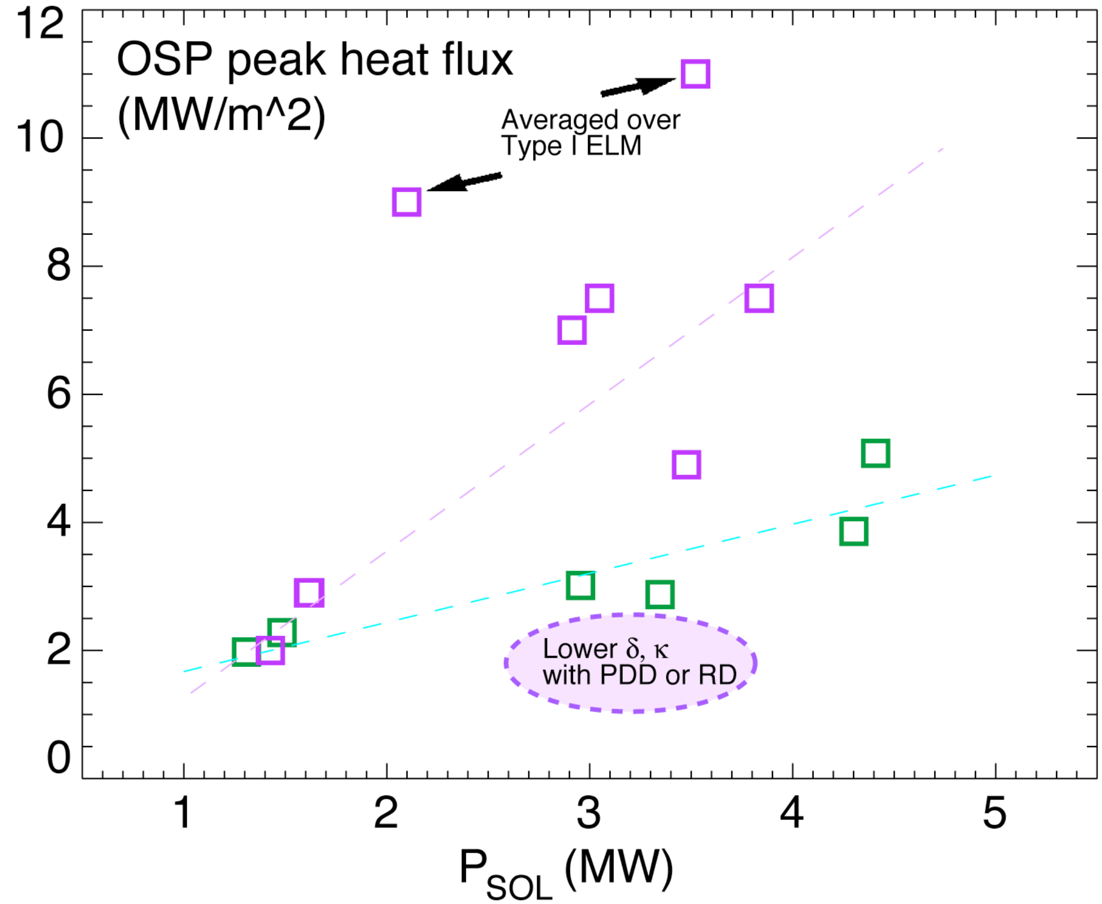
Publications and collaborations

- 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

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

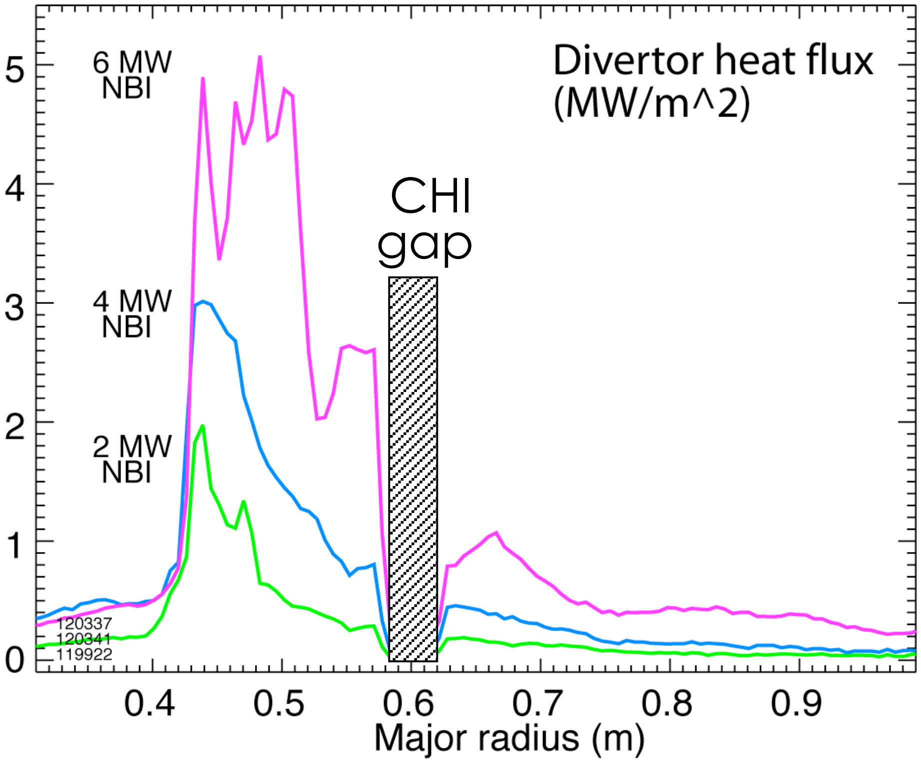


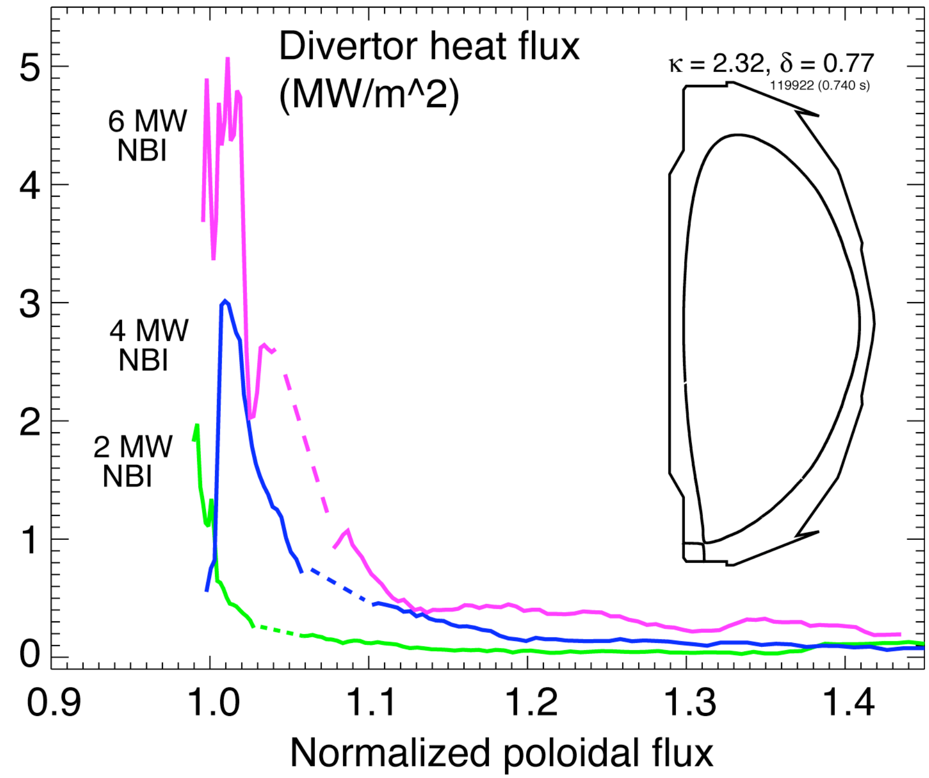


- Scaling depends on fueling location and gas injection rate
- P_{SOL} is determined from measured and TRANSP-calcualted quantities as

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

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

Run plan - overview

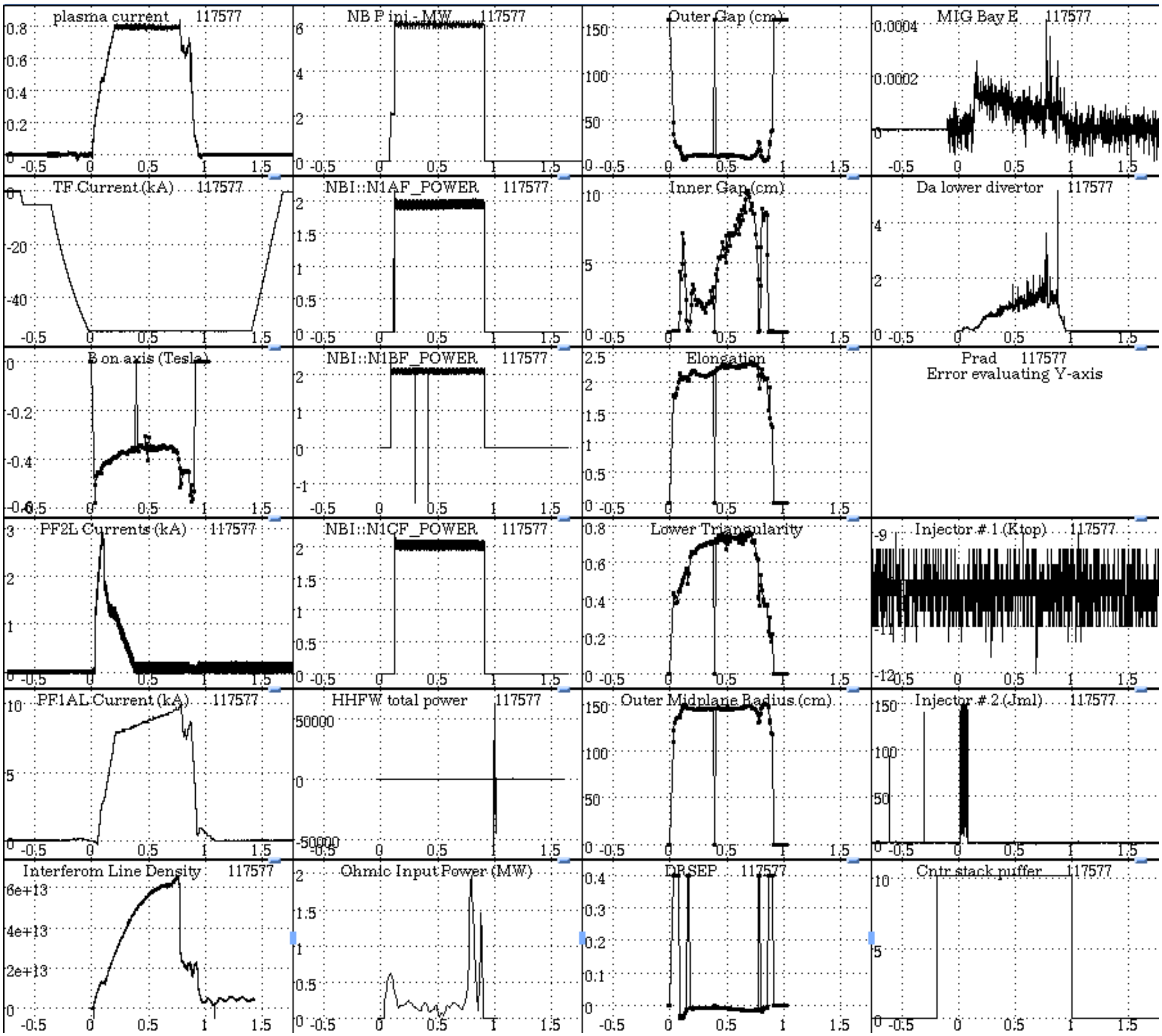
- **Divertor D_2 puffing (~ 0.5-0.7 day)**
  - Target plasma - 4-6 MW H-mode LSN plasma, 0.7-0.8 MA, 5 - 5.5 kG, δ~0.7-0.8, κ~2.3
  - Try 200-400 Torr l / s from LDGIS and 100-160 Torr l /s from Branch 5 injectors
  - Diagnostic set is ready

- **Extrinsic impurity puffing (CD_4 or N_2) (~ 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

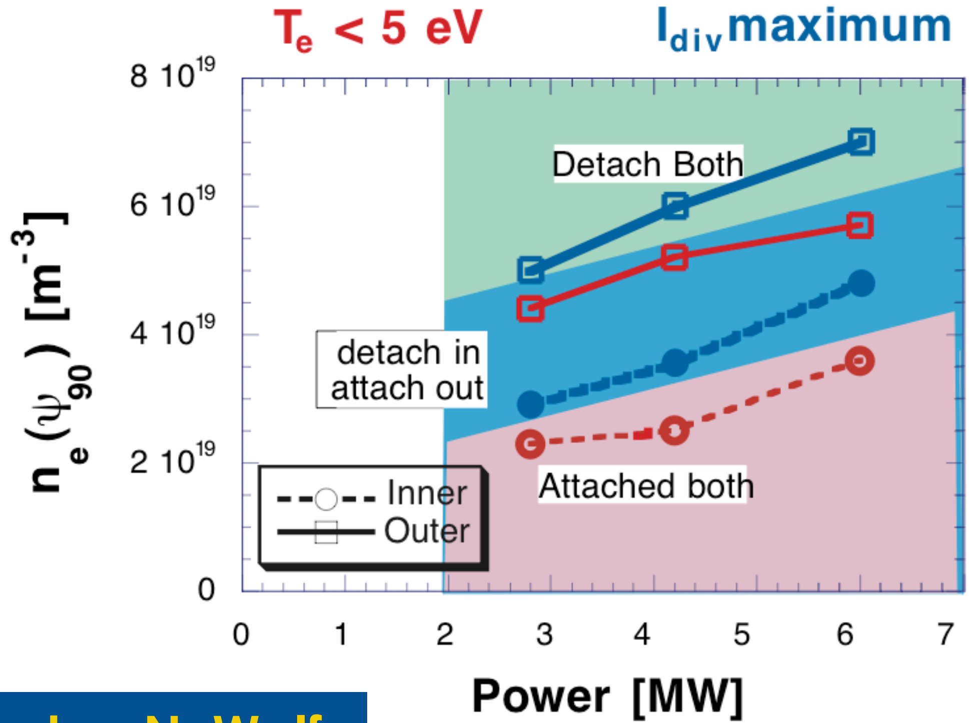
Shot template has been well developed



Back-up slides

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:

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

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

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

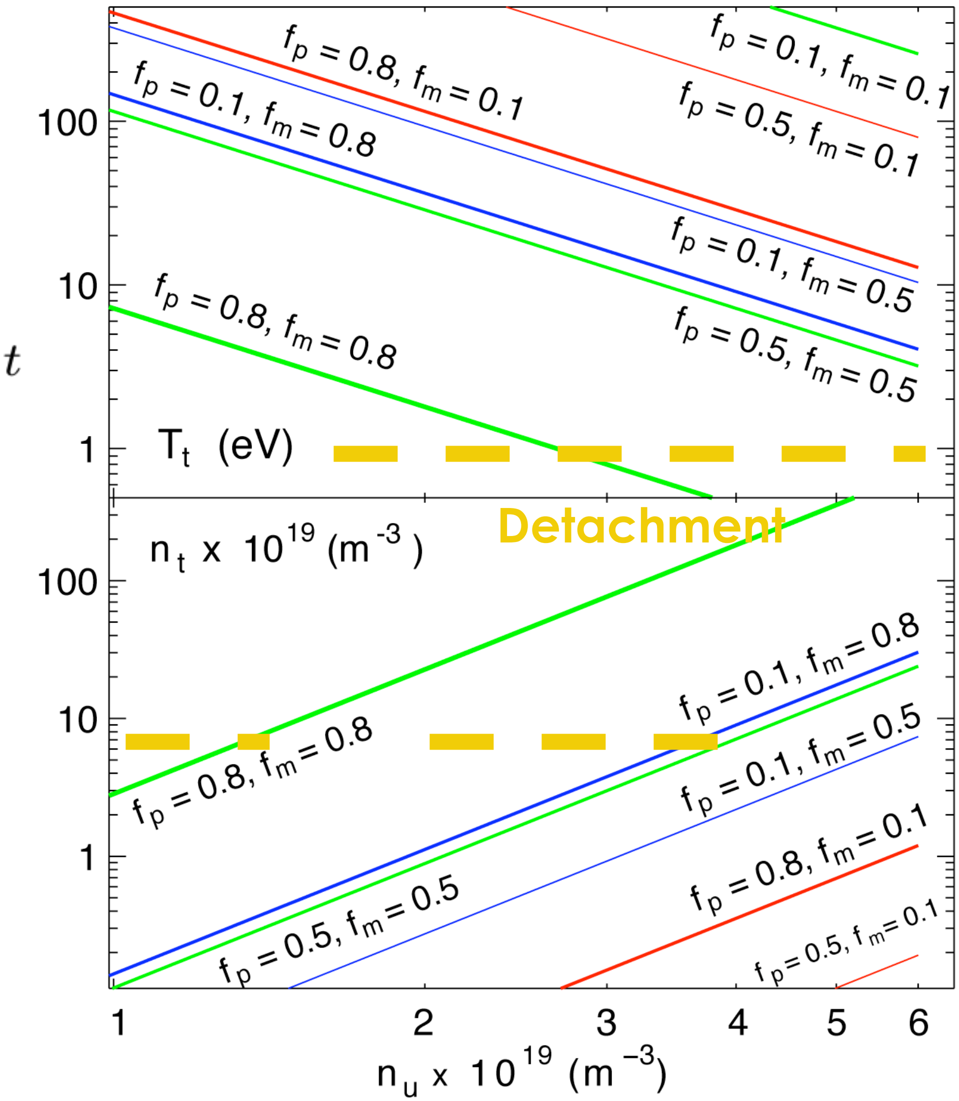
$$(1 - f_{power})\ q_{||} = q_t = \gamma\ T_t\ n_t\ c_{St}$$

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

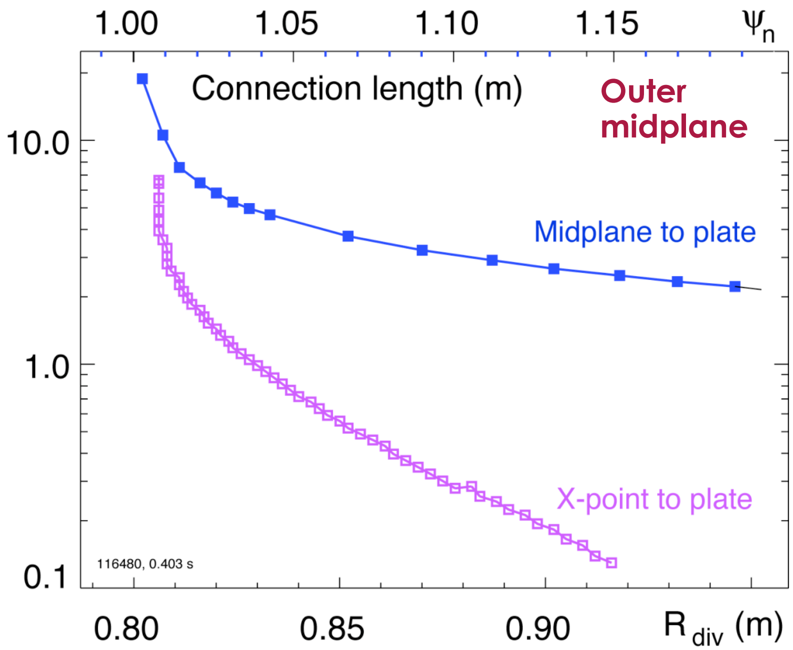
$$T_u^{7/2} = T_t^{7/2} + \frac{7}{2}\ \frac{f_{cond}\ q_{||}\ L_c}{\kappa_{0e}}$$

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

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

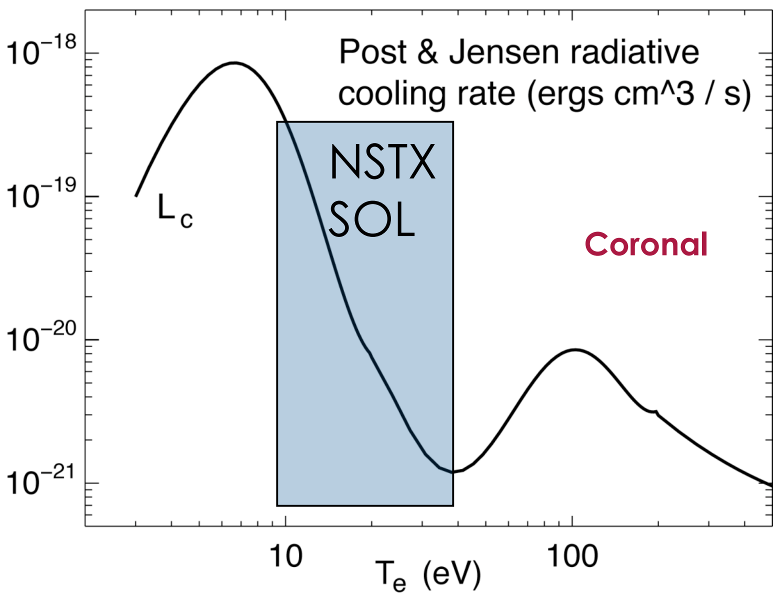


Why is it difficult to obtain OSP detachment?



- 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

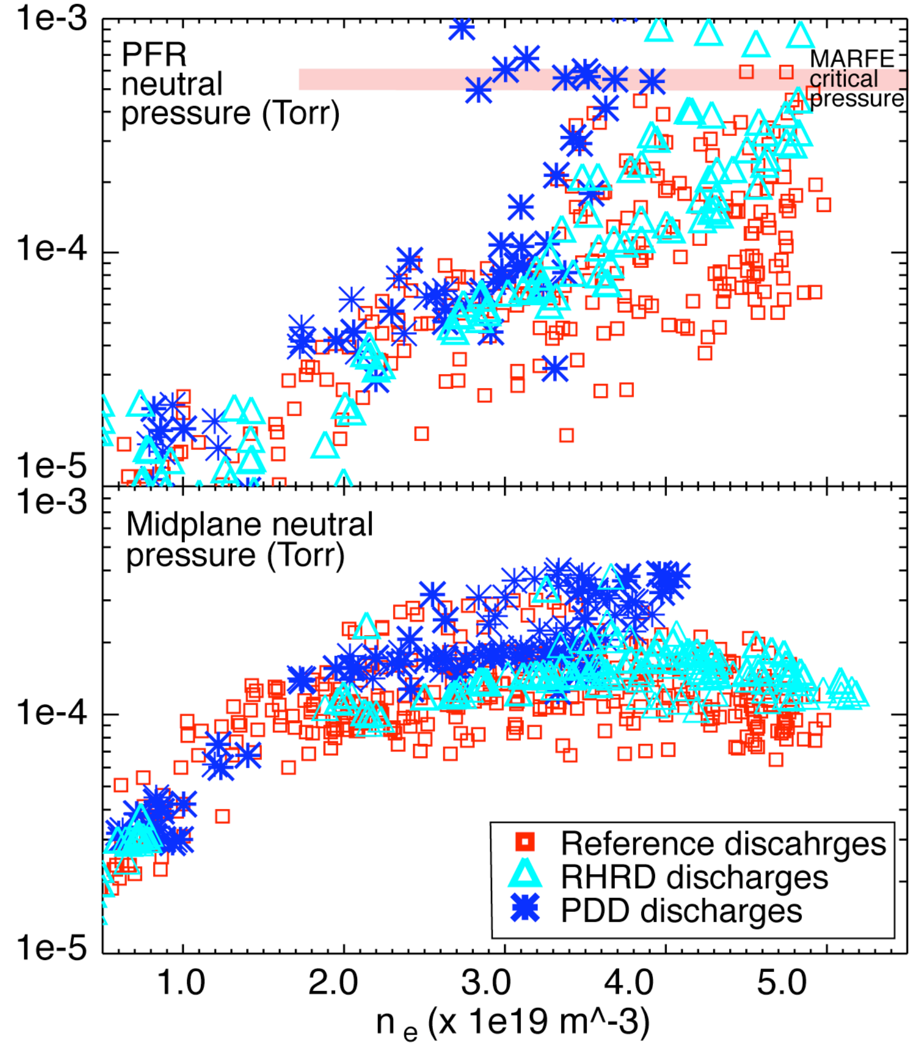


- Recombination time: $\tau_{rec} = 1./(n_e R_{rec}) \sim 1–10$ ms at $T_e = 1.3$ eV
  Ion divertor residence time: $\tau_{ion} = L_d/v_{ion} \sim 0.8$ ms (with $v_{ion} \sim 10^4$ m/s)

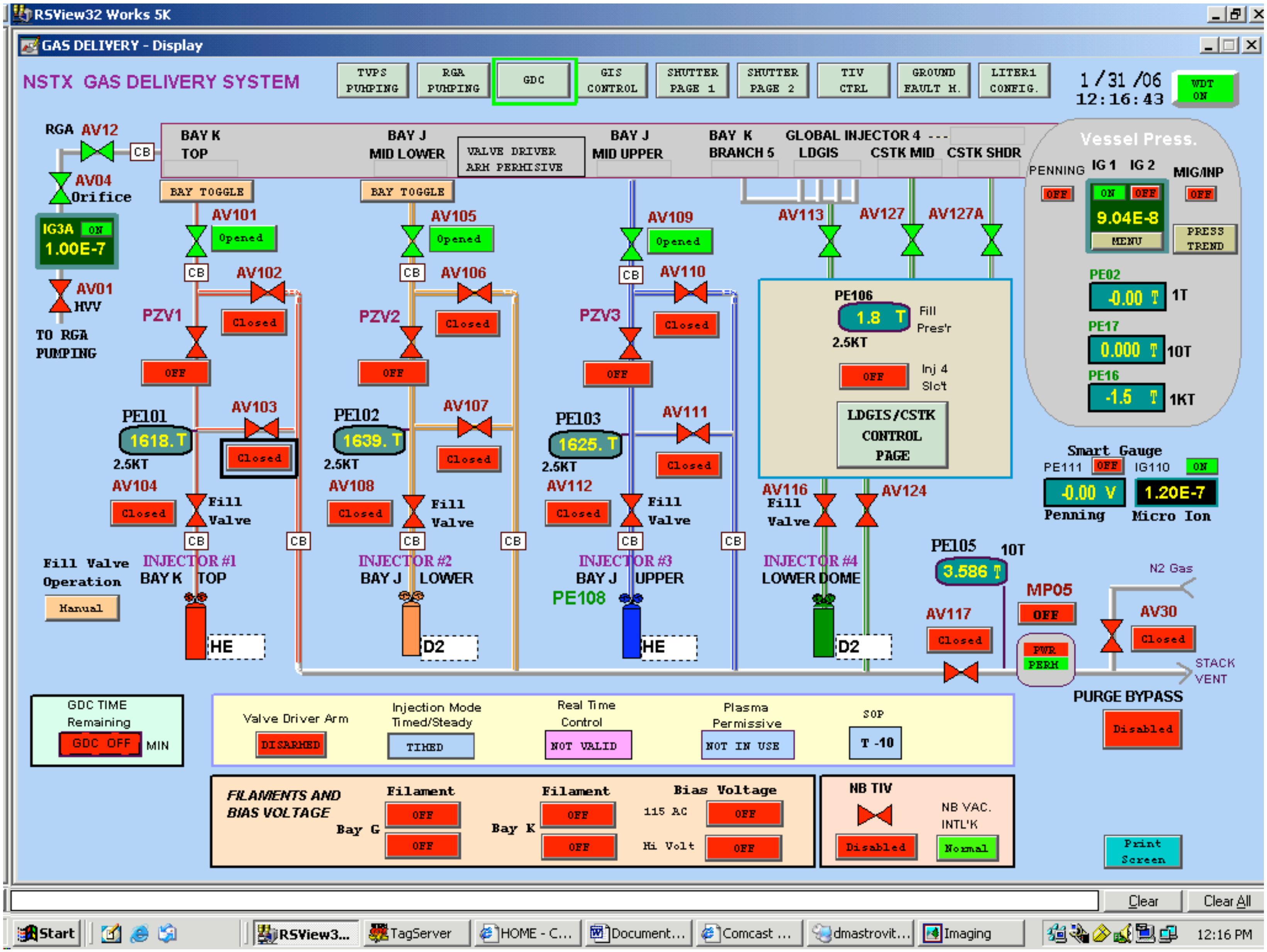
- Open divertor geometry - high detachment threshold is expected
- Neutral compression ratio is 5-10 (low)

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