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Radiative divertor in highly-shaped H-mode plasmas in NSTX

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Princeton, NJ

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FY 2008 radiative divertor experiment is likely to complete radiative divertor studies in NSTX

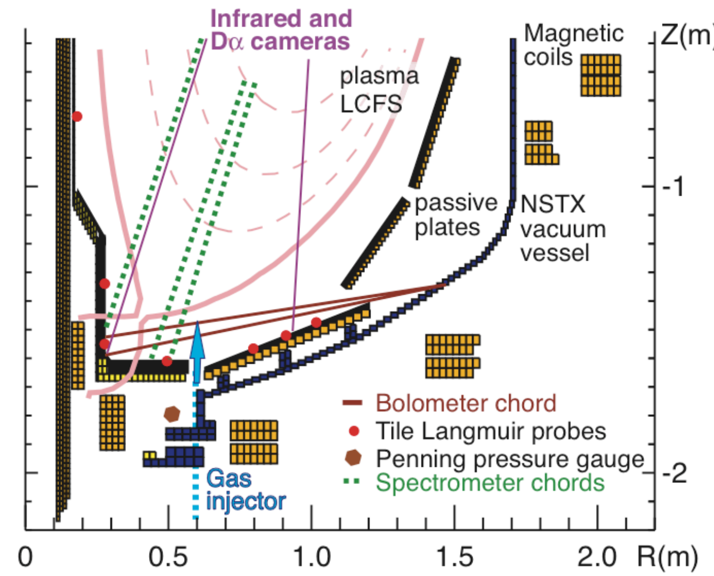
- Lithium coating experiments (FY 2008 - 2009) and liquid lithium divertor (FY 2009) will shift emphasis of divertor research to lithium work

- Lithium experiments make radiative divertor work impractical
  - Uncertainties in divertor q_{peak} and P_{rad} measurements
  - Different divertor transport regimes

- Proposed XP fits into the NSTX radiative divertor program in a logical way:
  - Divertor heat flux mitigation in low κ, δ configuration (2005-2006)
  - Divertor heat flux mitigation in highly-shaped configuration with D_2 injection (but also with intrinsic He) (2007)
  - **Divertor heat flux mitigation in highly-shaped configuration with D_2 and impurity injections (without intrinsic He) (2008)**

Multiple diagnostic measurements will be needed to elucidate on radiative divertor physics in NSTX

- Facility requirements:
  - Low Z_{eff}, low H/D
  - Reliable H-mode access
  - B_t up to 5.0 kG
  - New divertor gas injector (Bay E)
  - rtEFIT-controlled highly-shaped configuration for FY 2008



- Needed diagnostics:
  - IR cameras (upper/lower divertor heat flux)
  - Bolometers (core plasma and new divertor bolometers)
  - Dα, Dγ, C III divertor cameras
  - Neutral pressure gauges (incl. 3 lower div. Penning gauges)
  - Divertor Langmuir probes
  - MPTS, CHERS, ERD (n_e, T_e, n_c)
  - Spectroscopy (D I Balmer series, impurities)
  - Gas puff imaging

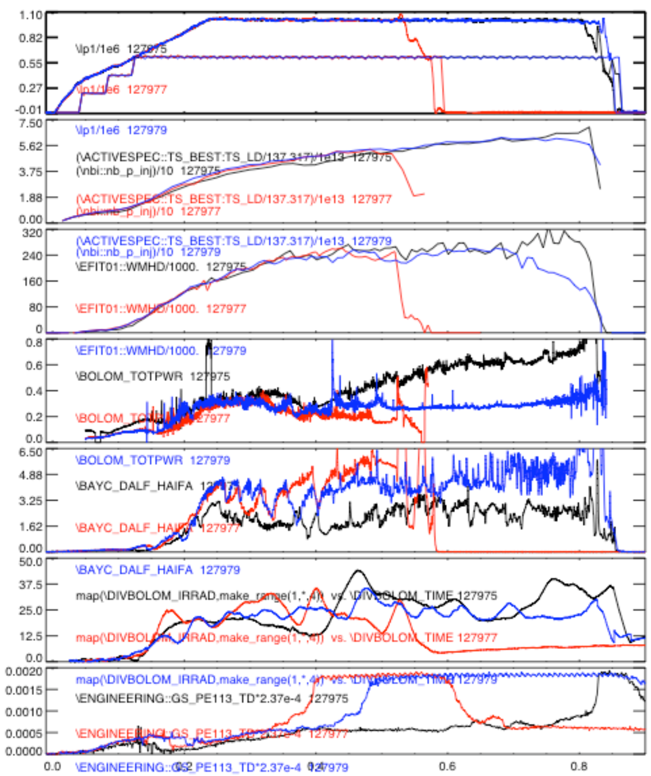
Radiative divertor XP: three parts involving different magnetic configurations and gas injections

- Obtain highly–shaped (κ = 2.2-2.3, δ = 0.65-0.75) **LSN** reference shot and reproduce **PDD conditions** at three I_p, P_{NBI} values **using D_2 injection** (up to 10 shots)
  - 1.0 MA, 6 MW part has been completed
  - Got started on 1.2 MA, 6 MW condition

- Obtain highly–shaped **DN** reference shot and obtain PDD conditions **using D_2 injection** at three I_p, P_{NBI} values using various gas injection rates (up to 10 shots)

- Obtain highly–shaped **LSN** reference shot and obtain PDD conditions **using He injection** (up to 10 shots)

Clear signs of peak heat flux reduction and detachment have been obtained in 1 MA, 6 MW shots



I_p (MA),
NBI (MW)/10

n_e(x 10^{19} m^{-3})

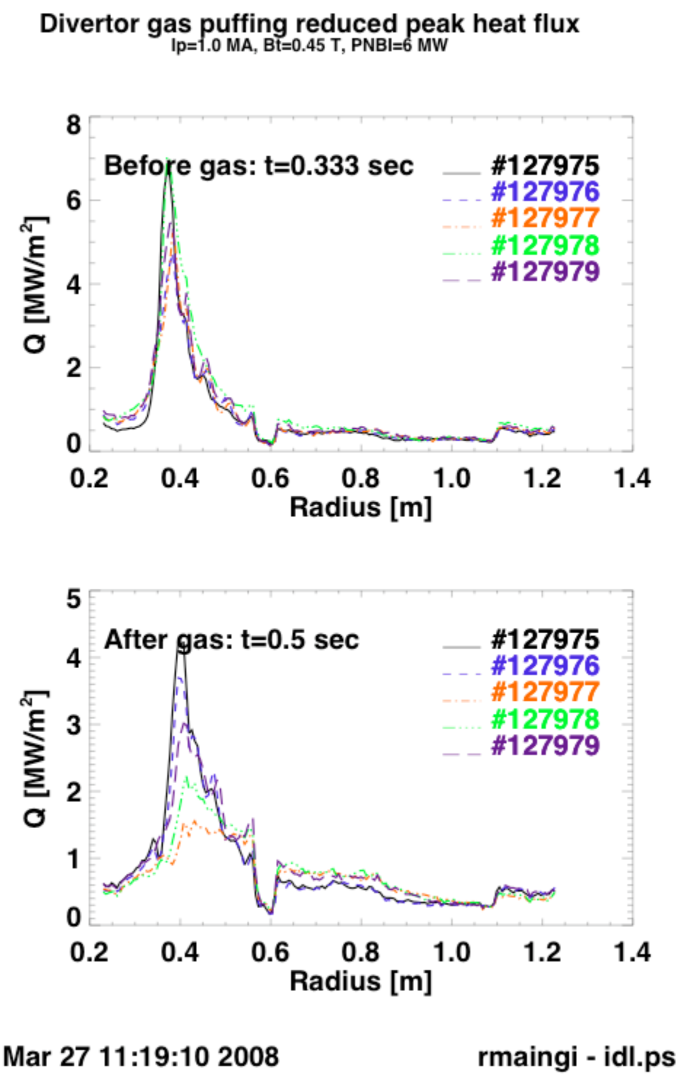
W_{MHD} (J)

P_{rad} (MW)

D_{α} (a. u.)

Div. bolo.

Div. Penning (Torr)



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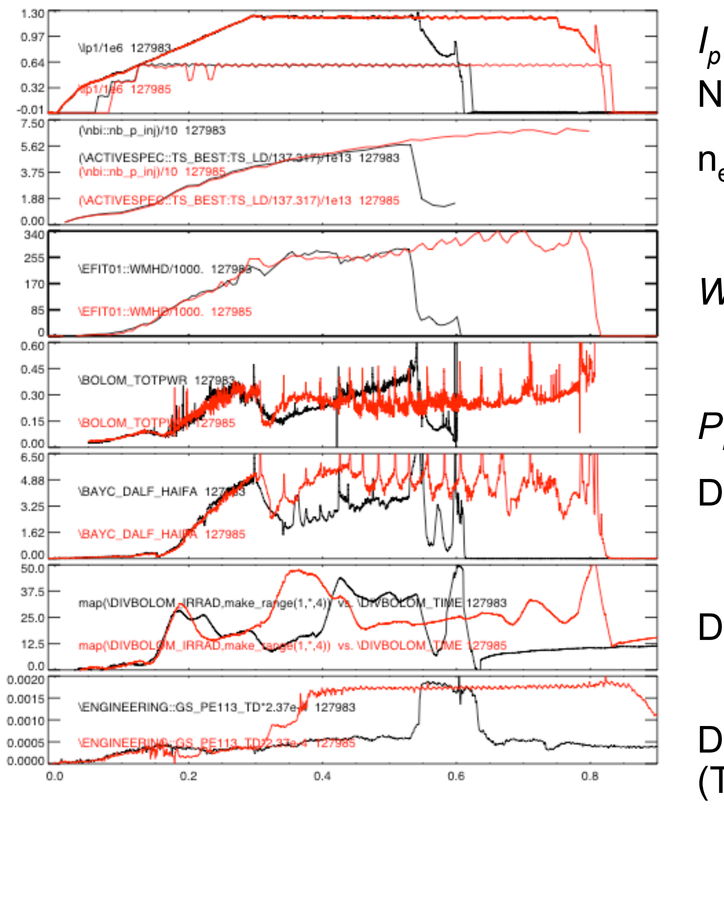
1.2 MA, 6 MW case will be pursued further



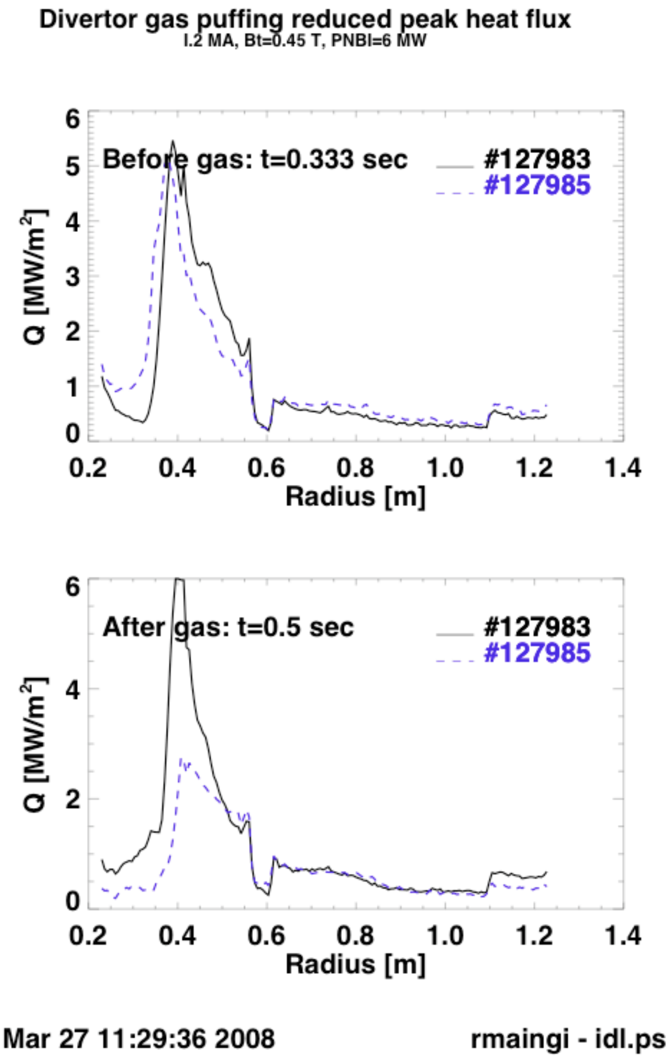
I_p (MA),
NBI (MW)/10
n_e(x 10^{19} m^{-3})

W_{MHD} (J)

P_{rad} (MW)
D_α (a. u.)

Div. bolo.

Div. Penning
(Torr)



Backup

Experiments in NSTX demonstrated several ways of divertor peak heat flux reduction

- **Divertor heat flux mitigation solutions:**
  - ✓ Poloidal flux expansion at outer strike point (OSP)
    - Particularly well suited for STs, reduced q_{peak} by up to 50 % in NSTX
  - ✓ Strike point sweeping (Plasma stability and control issues?)
  - ✓ Radiative divertor
    - reduced q_{peak} by up to 60 % in NSTX with D_2 injection (next slides)
  - ✓ Radiative mantle
    - reduced q_{peak} by up to 50 % in NSTX (w/ neon) albeit confinement degradation
  - ✓ Divertor materials and geometry (plate tilt, closure, number of divertors…)
- **These solutions must be compatible with good core plasma performance (H-mode confinement, MHD, ELM regime, density)**
- **Solutions must scale to very high q_{peak} (15 - 40 MW/m^2) for future devices (NHTX, ST-CTF)**
  - Combinations of solutions may work

Radiative divertor removes power and momentum from plasma before it reaches divertor plate

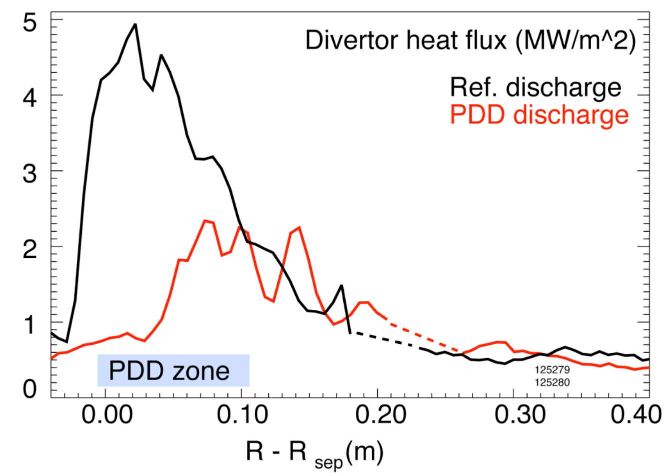
Parallel momentum and power balance

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

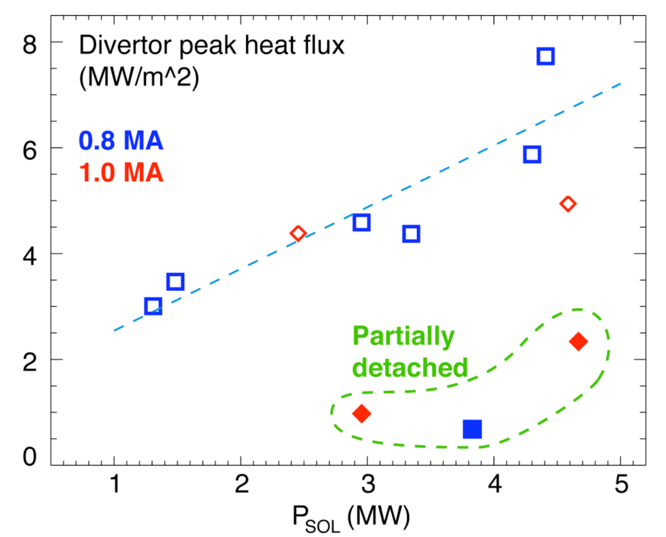
$$\frac{d}{ds}((-\kappa T_e^{5/2}\frac{dT_e}{ds}) + n v_{||}(\frac{5}{2}(T_i + T_e) + \frac{1}{2}m_i v_{||}^2 + I_0)) = S_E$$

Summary of FY 2007 radiative divertor results

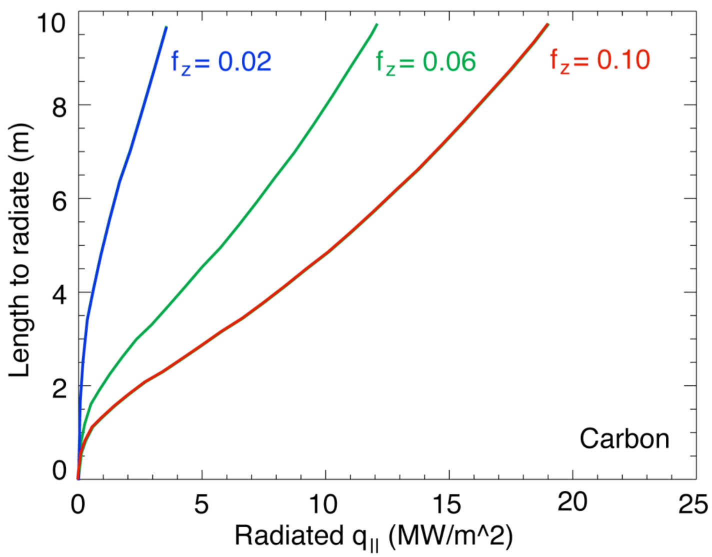
- Significant divertor **peak heat flux reduction** has been demonstrated in highly shaped high-performance H-mode plasmas in NSTX using **divertor magnetic flux expansion and radiative divertor** simultaneously with **high core plasma performance**
  - Good synergy of high performance small ELM H-mode regime with PDD



- Learnt detachment characteristics and limitations
  - Detachment achieved only with additional D_2 injection, or with additional low Z intrinsic impurities
  - PDD regime onset is abrupt. High radiated power, neutral pressure, volume recombination rate are measured
  - PDD properties appear to be similar to those observed in tokamaks



Impurity radiation role is to be clarified in radiative divertor experiments in FY 2008



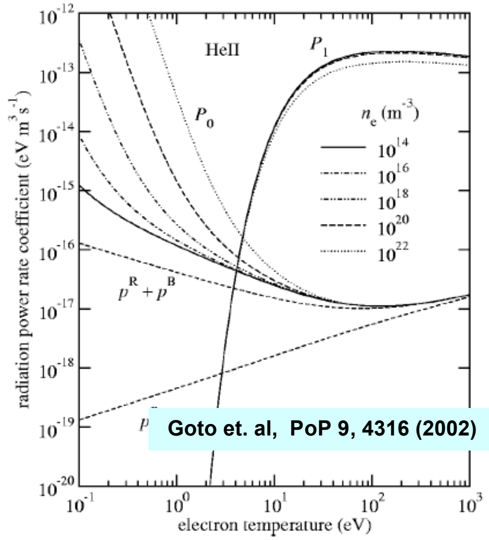
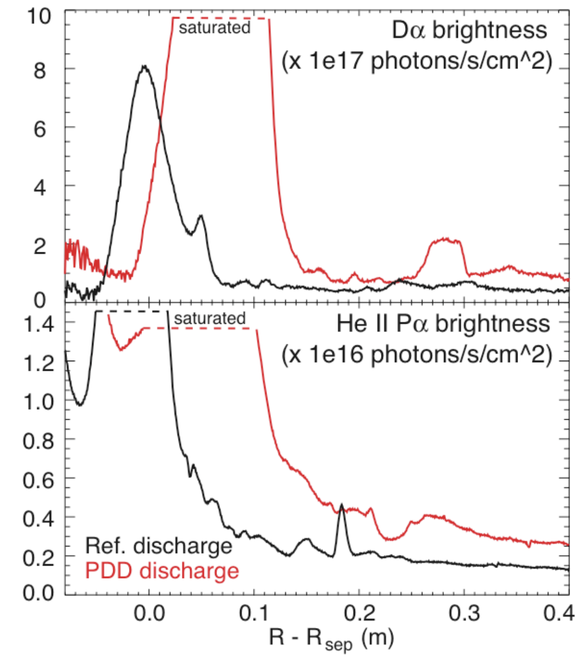


FIG. 14. T_e dependences of P_0 and P_1 for several n_e values for ionized helium.



- It is marginally possible to radiate the necessary fraction of $q_{||}$ with intrinsic carbon in NSTX
- Helium can play an important role in divertor power balance
  - Energy expensive (first I.P. 24.6 eV)
  - Radiates at 1-10 eV
- In FY 2007 experiment
  - Radiated power was due to deuterium, lithium, helium, and carbon
  - He and C were main contributors