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Divertor heat flux mitigation in highly-shaped H-mode discharges with radiative divertor (XP 814)

V. A. Soukhanovskii

Lawrence Livermore National Laboratory, Livermore, CA

Acknowledgments:

R. Maingi[1], D. Gates[2], J. Menard[2], C. E. Bush[1], R. Kaita[2], B. P. LeBlanc[2], S. F. Paul[2], R. Raman[3], A. L. Roquemore[2], and the NSTX Team

[1]*Oak Ridge National Laboratory, Oak Ridge, TN*
[2]*Princeton Plasma Physics Laboratory, Princeton, NJ*
[3]*University of Washington, Seattle, WA*

NSTX FY2008 Results Review
6 August 2008
Princeton, NJ

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

- **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

XP 814 experiment continued multi-year radiative divertor research effort on NSTX

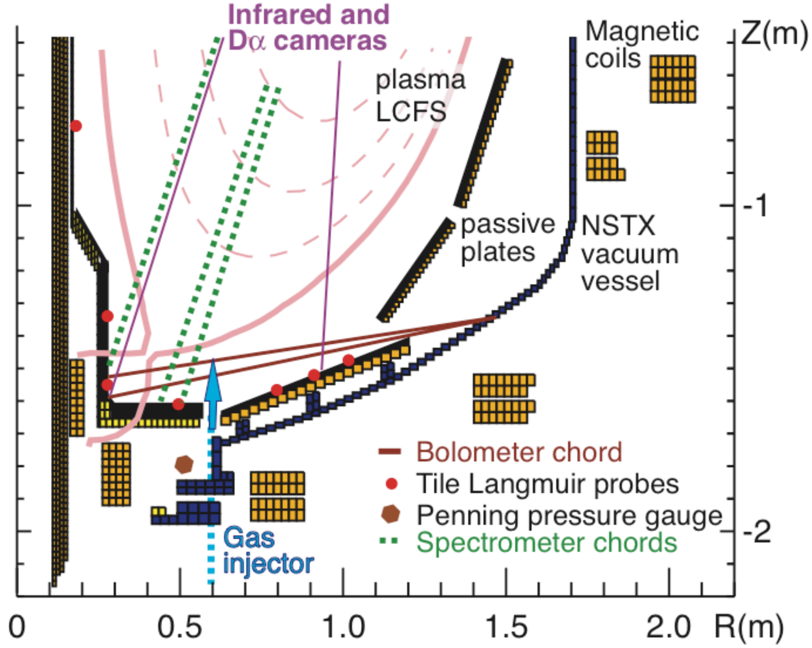
- Divertor heat flux mitigation in low κ, δ configuration (2004-2006)
  - Highest q_{pk}=10-12 MW/m^2 in 4-6 MW, 0.8 MA discharges
  - Peak heat flux reduced using gas injection, but confinement also degraded
- Divertor heat flux mitigation in highly-shaped configuration with D_2 injection (2007)
  - Reduced q_{pk} due to poloidal flux expansion
  - Demonstrated PDD regime with divertor gas injection and good confinement
  - Reduced q_{pk} by up to 60 % using divertor radiation from carbon and intrinsic helium
- **Divertor heat flux mitigation in highly-shaped configuration with D_2 and without intrinsic helium (2008)**
  - **Obtained optimized PDD regime with good core confinement in 6 MW, 1.0 MA and 6 MW, 1.2 MA discharges**
  - **Reduced q_{pk} from 6-15 MW/m^2 by 50-70 %**

Multiple diagnostic measurements are analyzed to elucidate on radiative divertor physics in NSTX

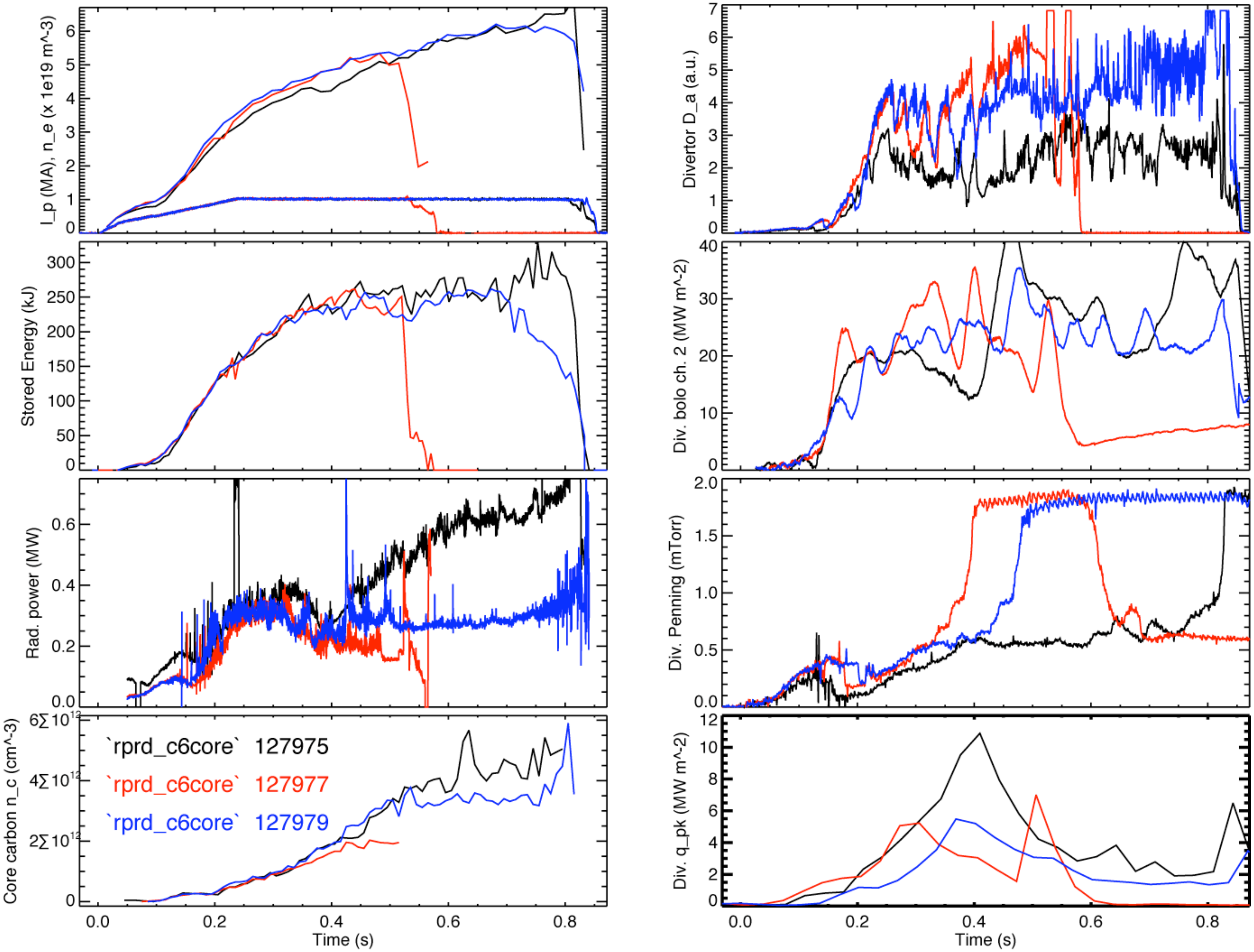
- Diagnostics used in this study:
  - IR cameras (upper/lower divertor heat flux)
  - Bolometers (core plasma and new divertor bolometers)
  - Dα, Dγ, C III divertor cameras
  - Neutral pressure gauges (incl. 3 lower div. Penning gauges)
  - Divertor Langmuir probes
  - MPTS, CHERS, ERD (n_e, T_e, n_c)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

- Highly-shaped (κ = 2.2-2.3, δ = 0.65-0.75) high-performance H-mode discharges with small ELMs

- Modeling:
  - Two point and 1-D SOL transport
  - UEDGE



Optimized PDD regime was obtained in 1 MA, 6 MW H-mode discharges



In PDD shots:

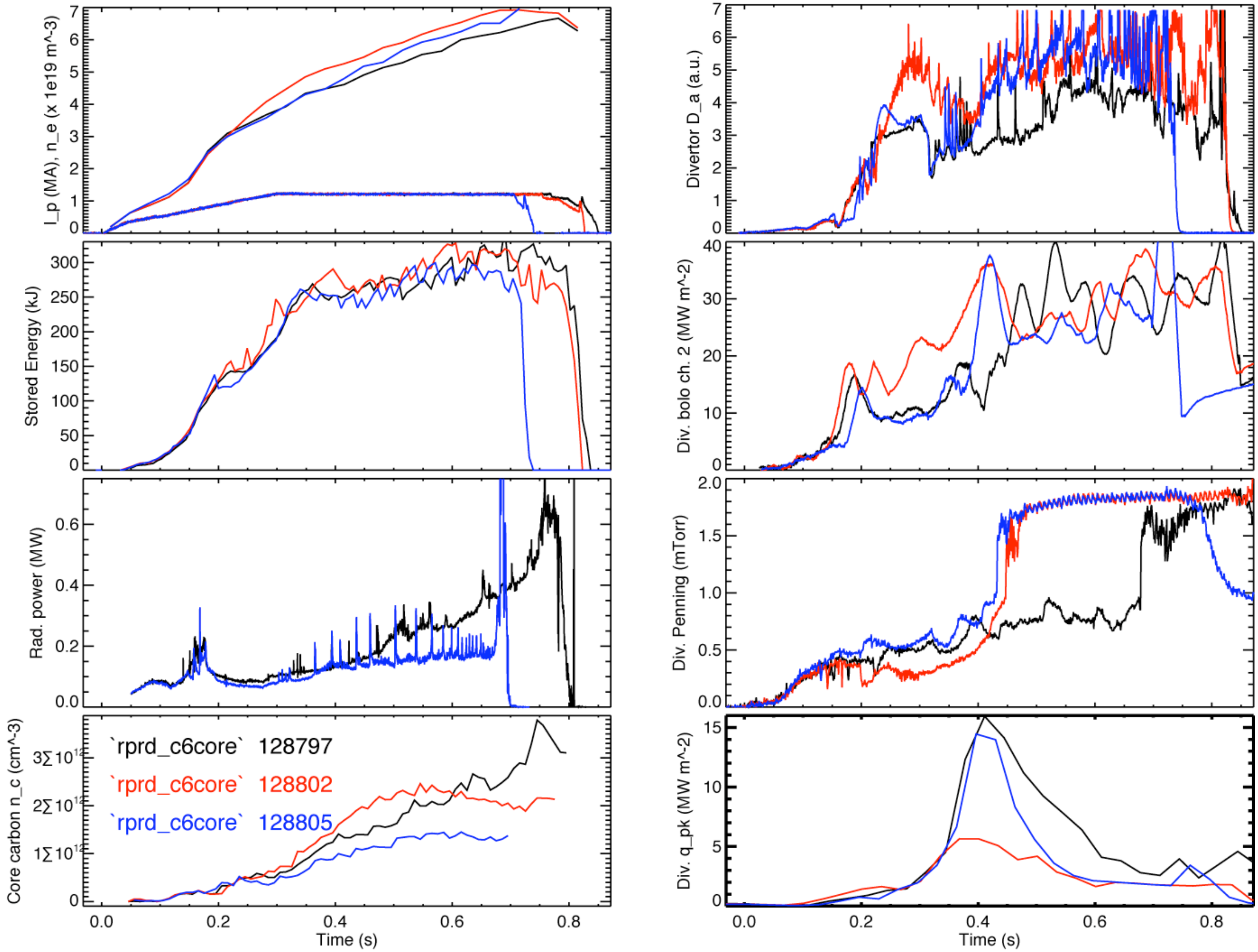
- Similar (+/- 10 %) density
- Same stored energy and confinement
- Reduced radiated power and core carbon density
- Increased divertor radiated power
- Increased divertor neutral pressure
- Reduced divertor peak heat flux

Ref. shot

PDD shot with div. gas at 4400 Torr

Optimized PDD shot with div. gas at 2900 Torr

In 1.2 MA, 6 MW discharges reduction of very high q_{pk} required higher gas puffing rate



In PDD shots:

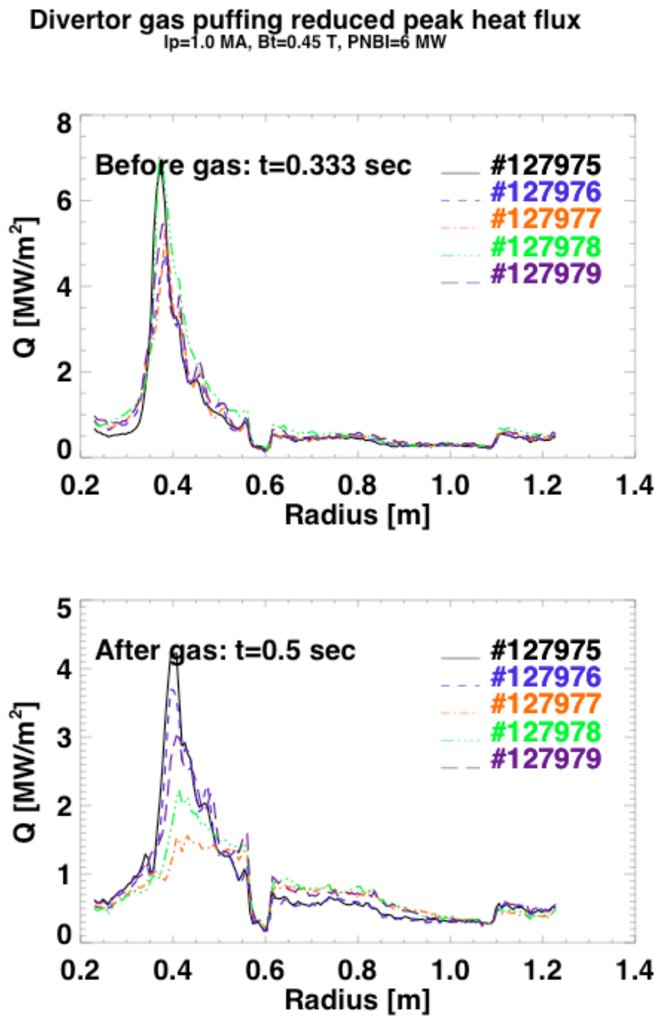
- Similar (+/- 10 %) density
- Same stored energy and confinement
- Reduced radiated power and core carbon density
- Increased divertor radiated power
- Increased divertor neutral pressure
- Reduced divertor peak heat flux

Ref. shot

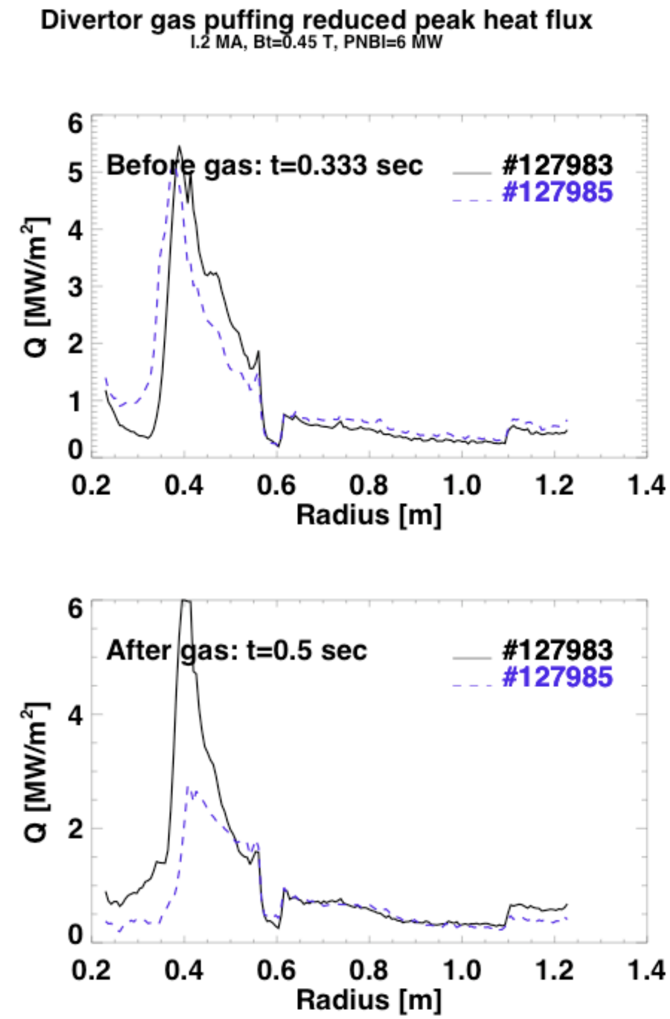
PDD shot with div. gas at 4000 Torr

Optimized PDD shot with div. gas at 4700 Torr

Divertor heat flux profiles show significant heat flux reduction in both 6 MW/1 MA & 6 MW/1.2 MA cases



6 MW, 1.0 MA



6 MW, 1.2 MA

Conclusions

- Analysis is in progress to interpret successful radiated divertor experiments in highly shaped 6 MW, 1.0-1.2 MA H-mode discharges
  - Role of divertor radiation in SOL power balance
  - Role of recombination and charge exchange in momentum balance
  - Role of divertor geometry

- Future direction – radiative LLD !
  - Preliminary results obtained in 2008
  - Role of LLD pumping and new divertor regime
  - Radiative divertor with impurity injection

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Development and characterization of high flux expansion divertor in NSTX (part of XP 816)

V. A. Soukhanovskii

Lawrence Livermore National Laboratory, Livermore, CA

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[1]*Oak Ridge National Laboratory, Oak Ridge, TN*
[2]*Princeton Plasma Physics Laboratory, Princeton, NJ*
[3]*Nova Photonics, Princeton, NJ*
[4]*University of Washington, Seattle, WA*

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NSTX PCS and present divertor coil configuration enable divertor geometry studies

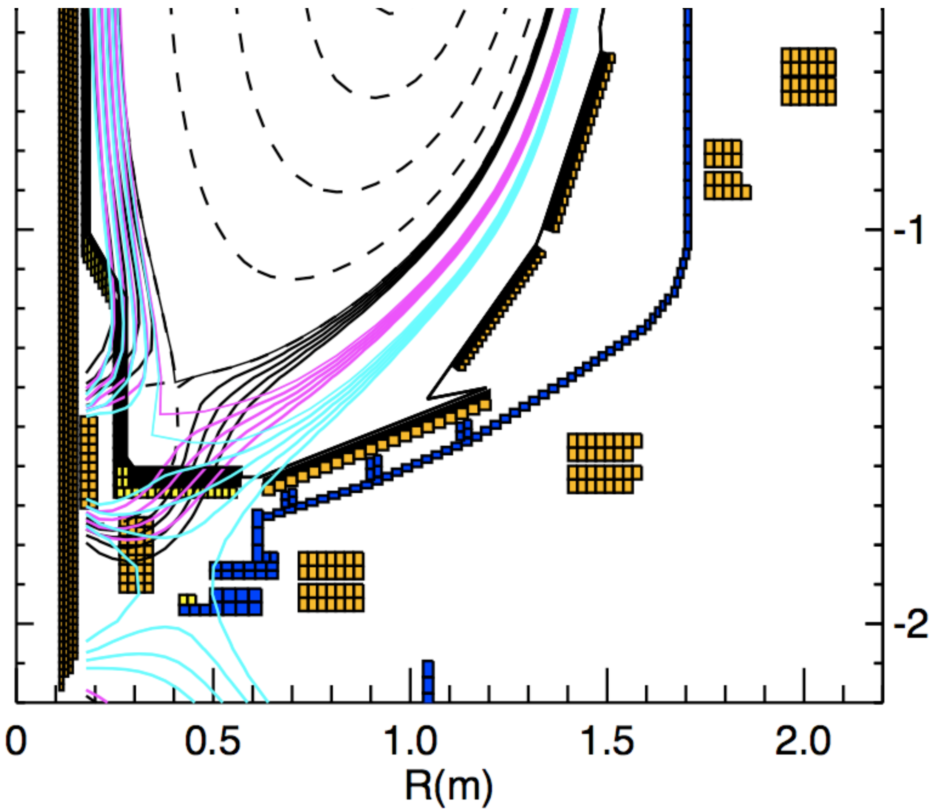
- Divertor poloidal flux expansion: $f_m=(B_\theta /B_{tot})^{MP\text{-}SEP} / (B_\theta/B_{tot})^{OSP}$
- Use divertor coils PF1A and PB1B to change f_m and L_{II}

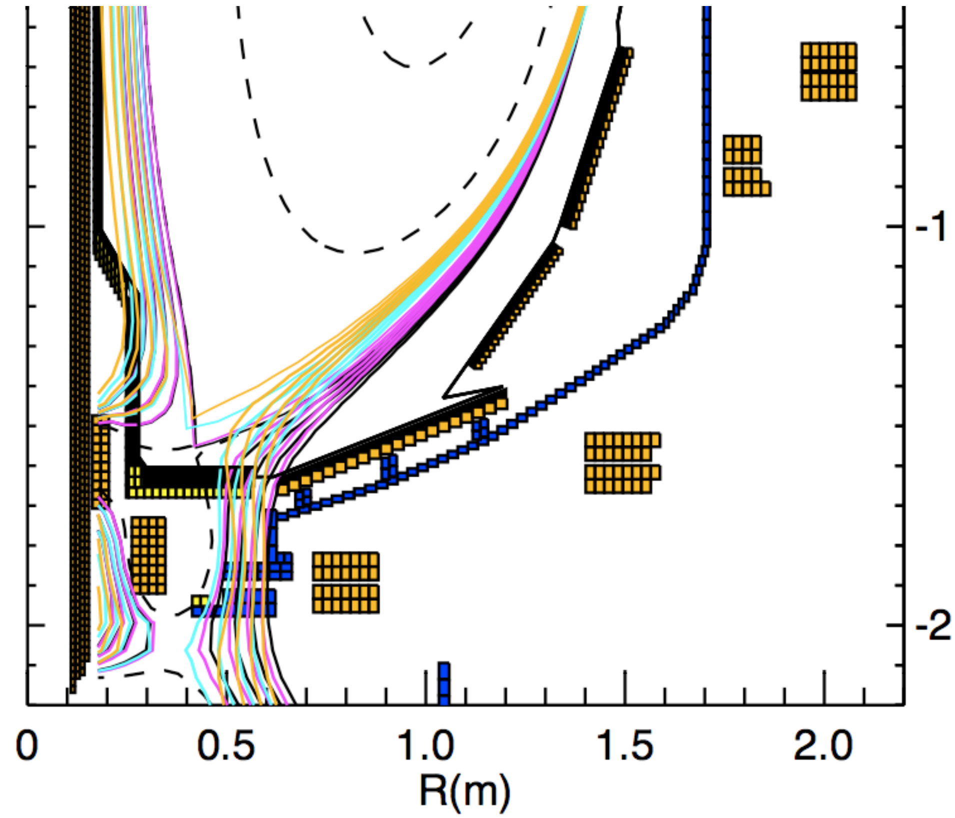
- Used ISOLVER (courtesy of J. Menard, D. Gates) to model equilibria for various PF1A and PF1B coil current trends

- Study as a function of f_m and L_{II}
  - Power balance and Divertor heat flux
  - Recycling, carbon sputtering and recombination rates
  - Ion momentum balance
  - Neutrals behavior, plasma “plugging effect”
  - Role of gyro-radius and MFP effects

- Goal – understand and predict divertor performance and limitations of X- and “snowflake” divertors with very high flux expansion (see NSTX 5-year plan)

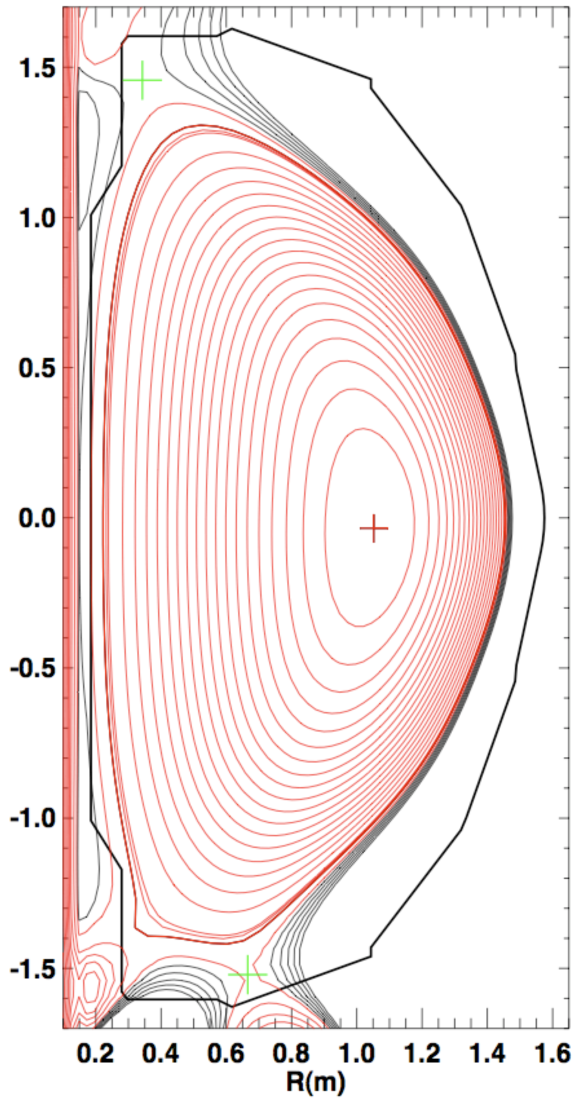
Divertor diagnostic data from divertor flux and area expansion scans are being analyzed





Coils	X-pt height	OSP major radius	Flux exp.
PF1AL	5-12 cm	0.33-0.40 m	18-22
PF1AL & PF1B	4-12 cm	0.38-0.42 m	17-22

On-going modeling to study “snowflake” configuration in NSTX



- Originally proposed by D. D. Ryutov
- Possible to obtain with existing divertor coils
- SOL transport is studied with UEDGE at LLNL
- Planning to propose experiment for FY 09 run