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XP 956 – SOL and divertor transport studies with reversed TF

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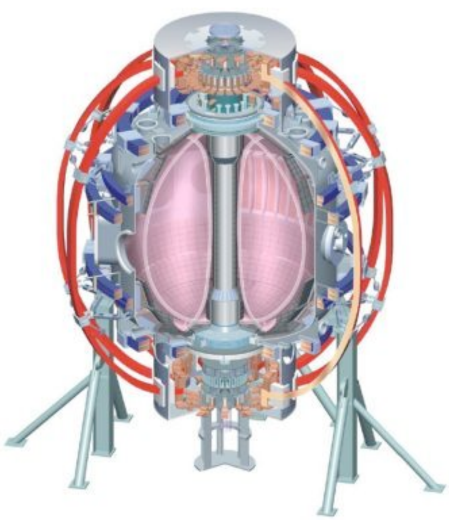
V. A. Soukhanovskii, LLNL

Acknowledgements: NSTX Research Team

NSTX Results and Theory Review

Princeton, NJ

15 September 2009



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A successful reversed TF campaign has been run

- Configuration:
  - TF was 4.5 kG
  - Forward B_t direction: CW from above, B x grad B toward lower X-pt
  - Forward I_p direction CCW from above (co-dir. w/ NBI)
  - Reversed B_t direction: CCW from above, B x grad B away from lower X-pt

- XP 956 provided initial results on
  - NSTX machine performance with reversed TF
  - data to motivate future reversed TF and possibly reversed I_p exp'ts
  - data to compare to large aspect ratio tokamaks (e.g., DIII-D, JET, AUG, JT-60U)

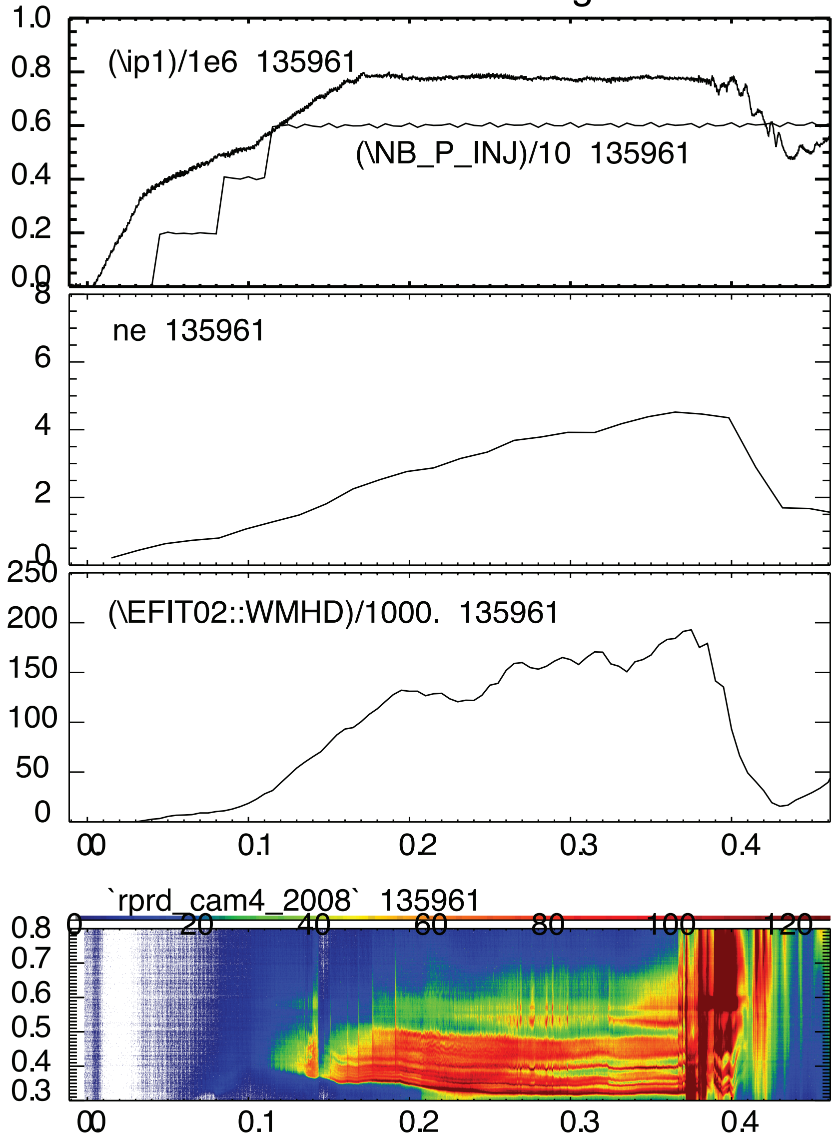
Summary

- Obtained SOL / divertor database in low δ configuration with lithium at several I_p and P_{NBI}
  - ✓ Observed decreased heat and particle flux asymmetries
  - ✓ Studied divertor detachment – no OSP detachment at gas puffing rate 200-350 Torr l / s (also, due to lithium pumping?). At highest rate, barely saw some signs of recombination in inner divertor
  - ✓ Need 2D fluid code modeling to understand magnitude of reversed drifts

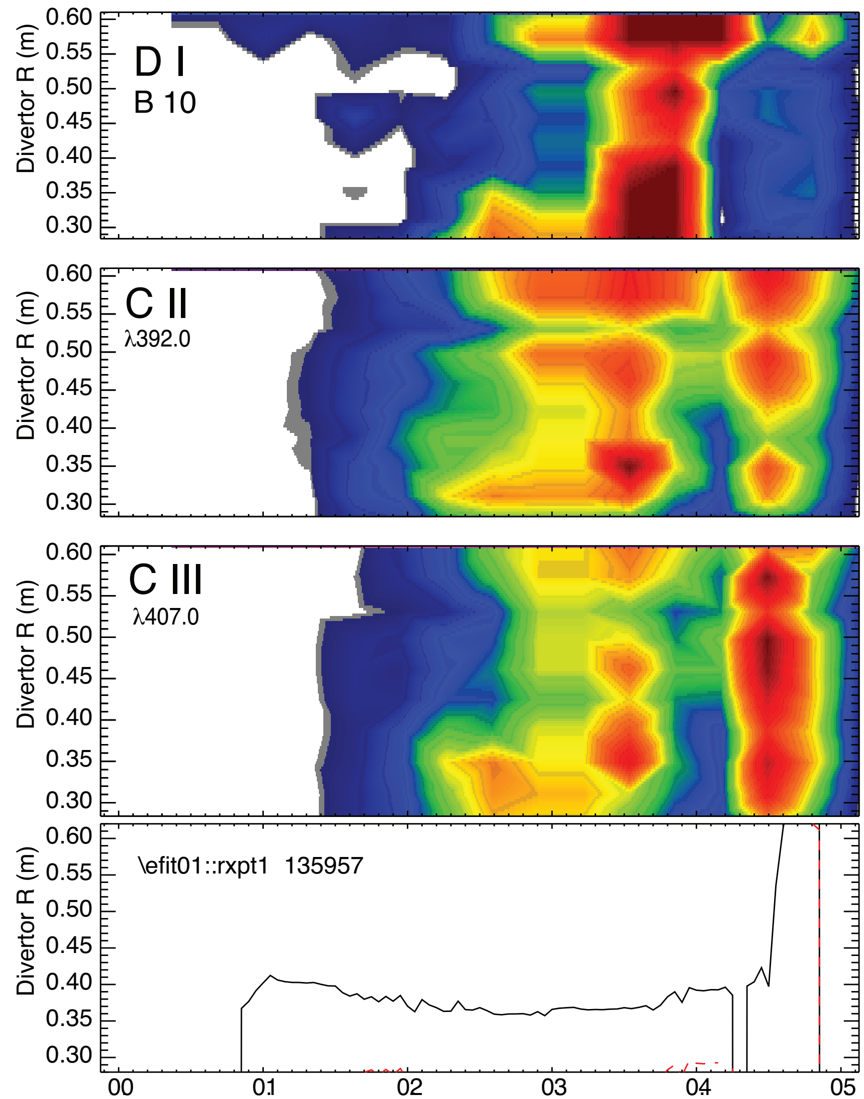
- Obtained SOL / divertor database in high δ configuration with lithium
  - ✓ Obtained divertor heat / particle fluxes at P_{NBI}=1-6 MW
  - ✓ Studied divertor detachment – apparently obtained OSP partial detachment
  - ✓ Observed high degree of OSP splitting

Data analysis of radiative divertor database at reversed TF is in progress

Reference discharge

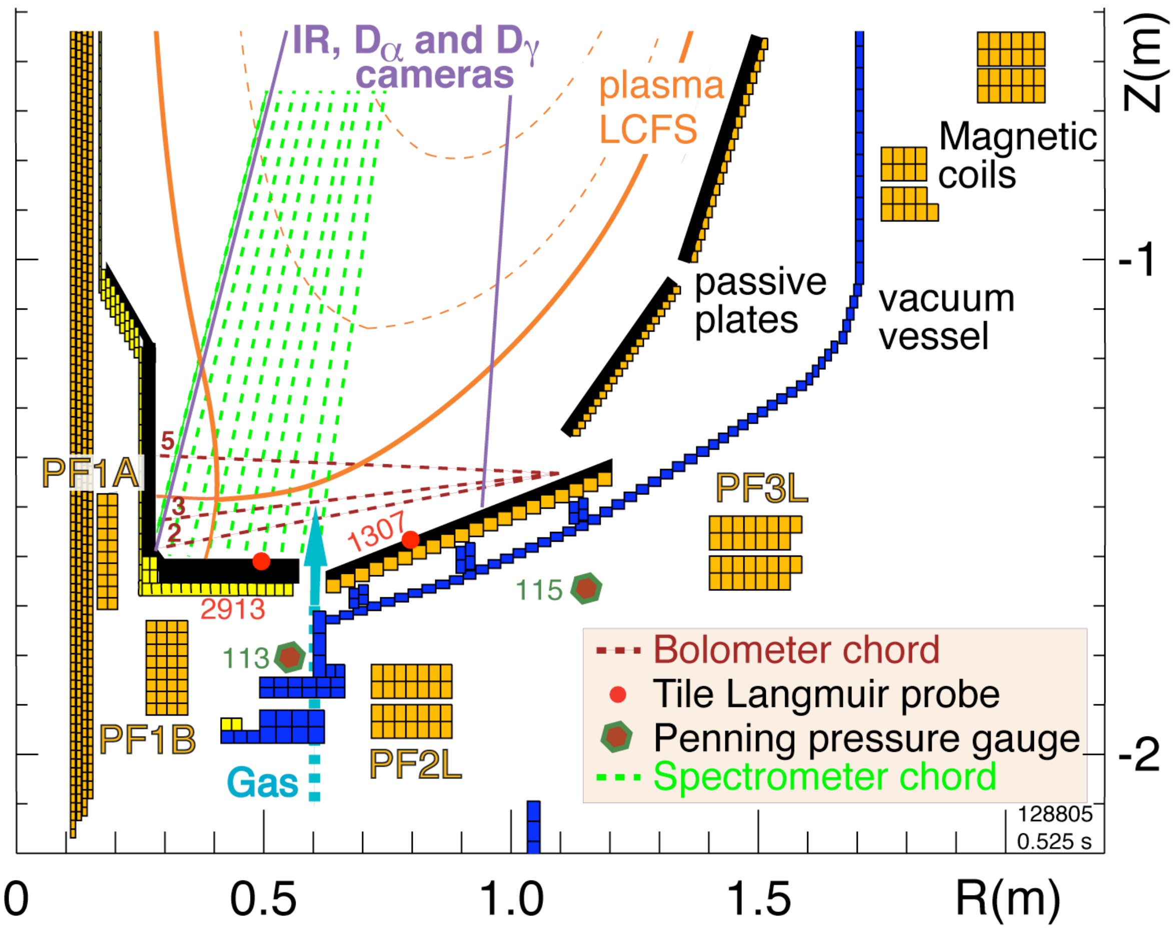


Divertor profiles with gas inj. starting at 0.22-0.25 s



NSTX edge diagnostics set is (well?) suited for the proposed SOL and divertor studies with reversed B_t

- Diagnostic set for divertor studies:
  - IR cameras
  - Bolometers
  - Neutral pressure gauges
  - Tile Langmuir probes
  - D_α, D_γ filtered CCD arrays
  - UV-VIS spectrometer (10 divertor chords) – C II, CIII, Balmer, He profiles
  - Fast cameras
- Midplane Thomson scattering and CHERS systems
- Divertor gas injector Γ_{gas} = 20-200 Torr l / s



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XP 912 – Comparison of H-mode fueling with supersonic gas injector and conventional gas injector

V. A. Soukhanovskii, LLNL

Acknowledgements: R. Raman (U.Washington), R. Bell, R. Kaita, H. W. Kugel, B. LeBlanc, J. E. Menard, D. Mueller, A. L. Roquemore, R. Maingi (ORNL) and the NSTX Research Team

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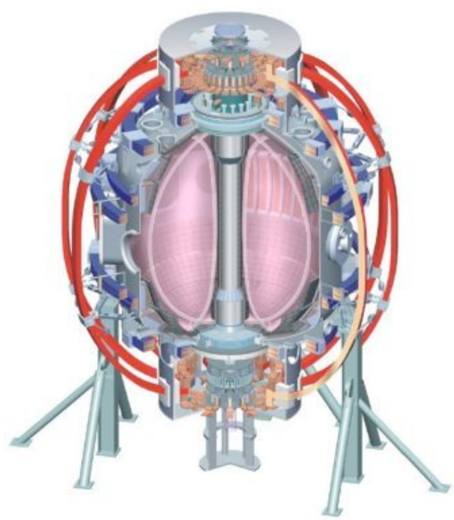

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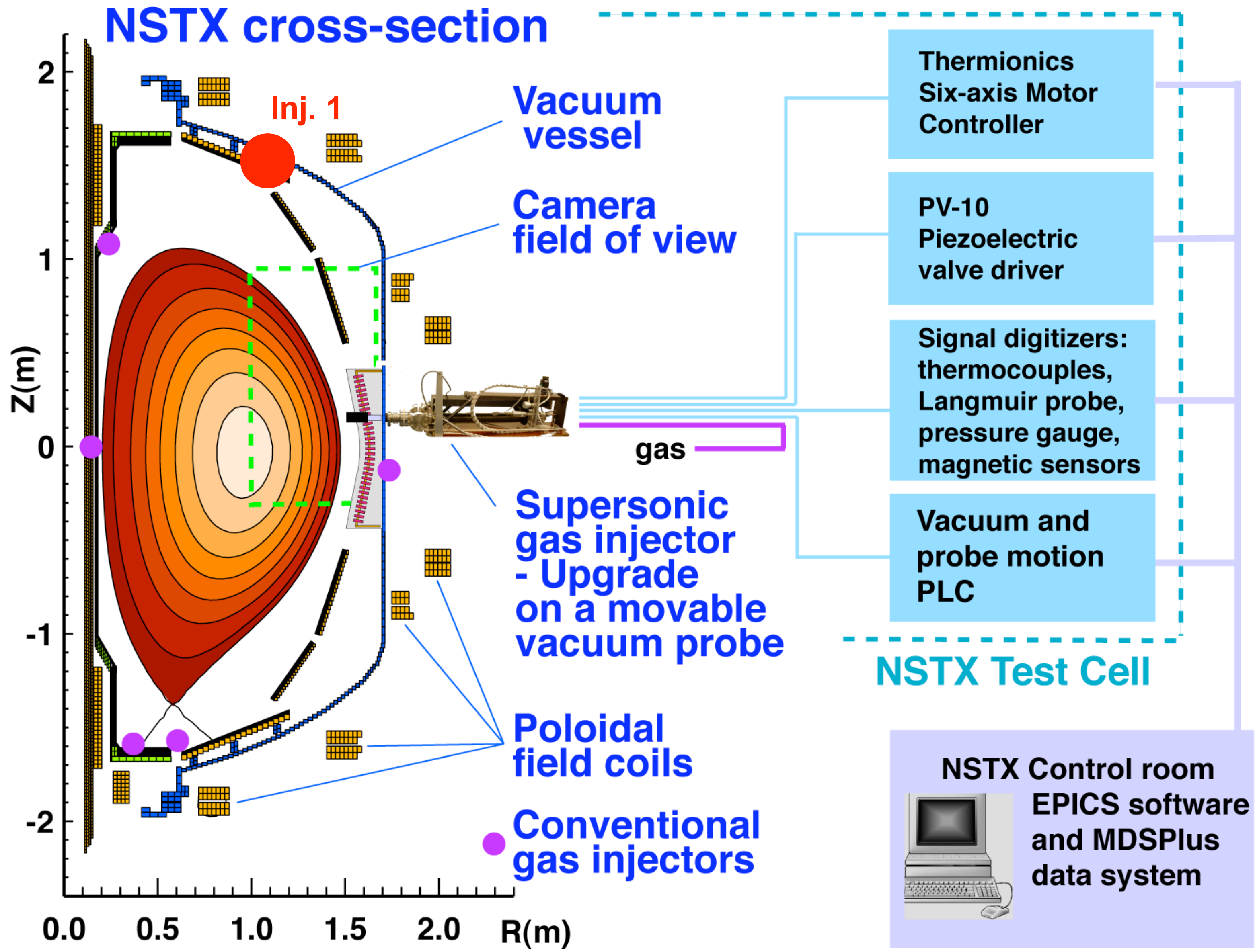
Motivation and Summary of XP 912

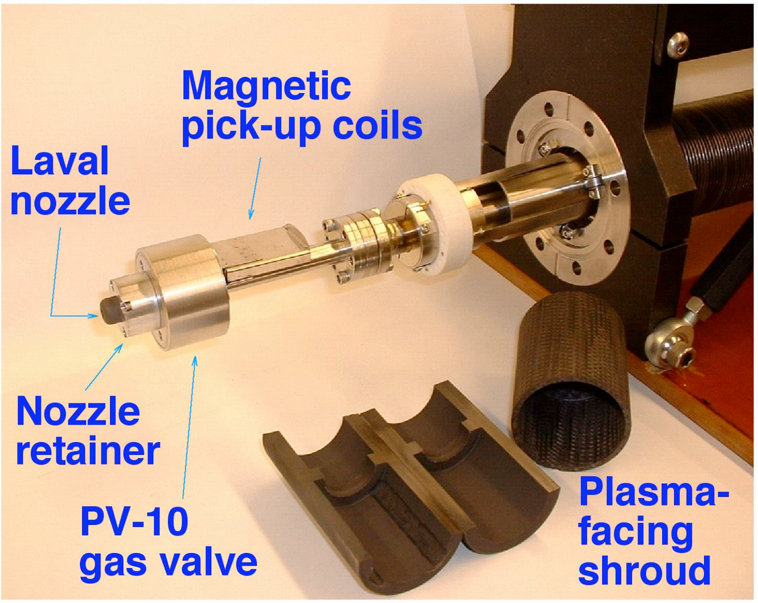
- Goals
  - develop H-mode fueling scenarios with SGI fueling and lithium pumping
  - study SOL, divertor and pedestal during supersonic gas jet fueling for further SGI optimization
  - compare with conventional gas fueling

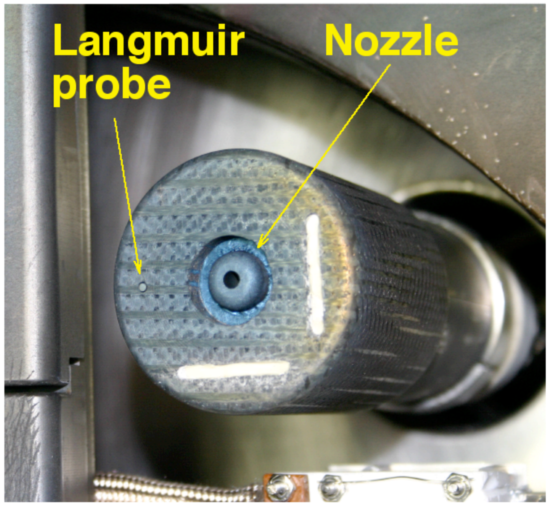
- Results
  - Comparison of conventional LFS gas fueling at 80, 120 and 200 Torr l /s and LFS SGI fueling showed that x 1.3-2 higher rate needed for conventional gas to maintain same density (and inventory)
  - Developed 0-HFS fueling scenario for H-mode with lithium (very robust) and used in several other XPs
  - With lithium pumping, apparently higher divertor density threshold for X-point MARFE formation – thus, SGI and lithium work very well

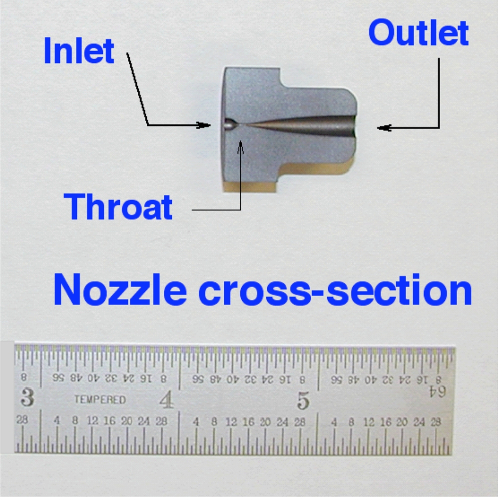
Supersonic gas injector is a complex computer-controlled high gas pressure apparatus



Supersonic gas injector consists of Laval nozzle and piezoelectric valve

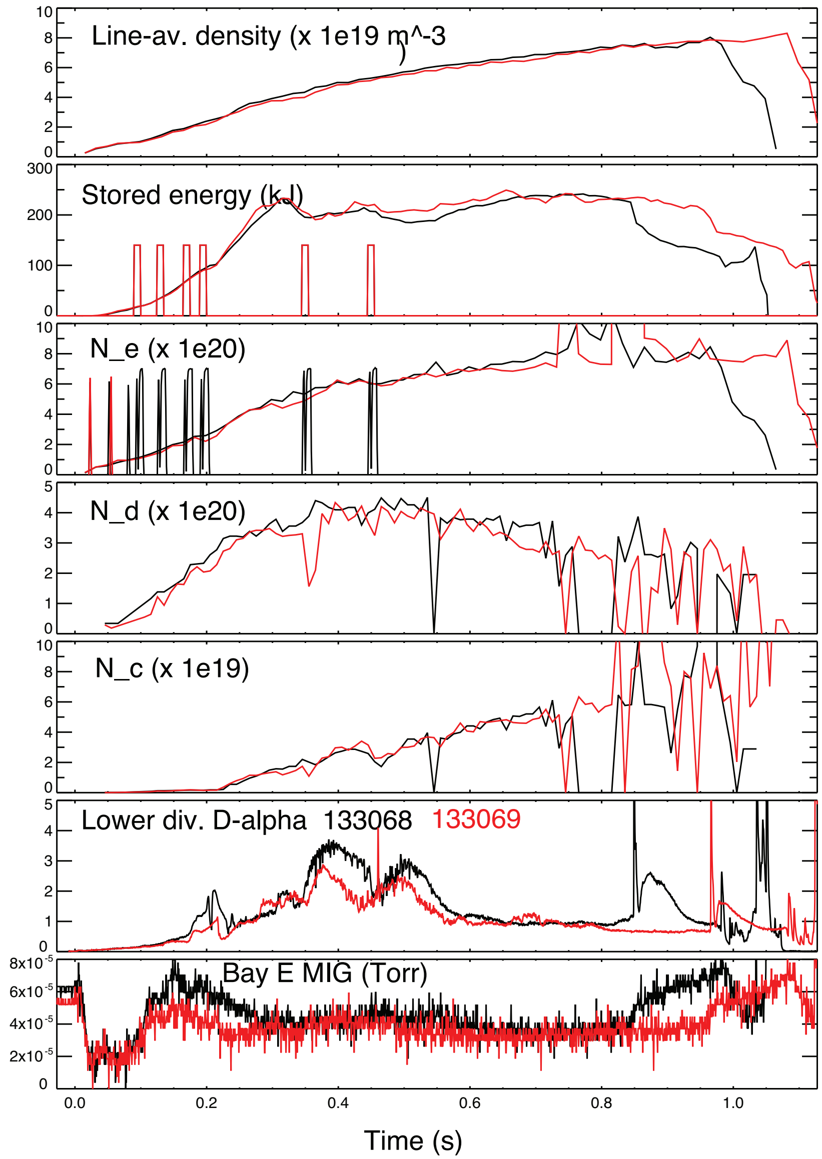




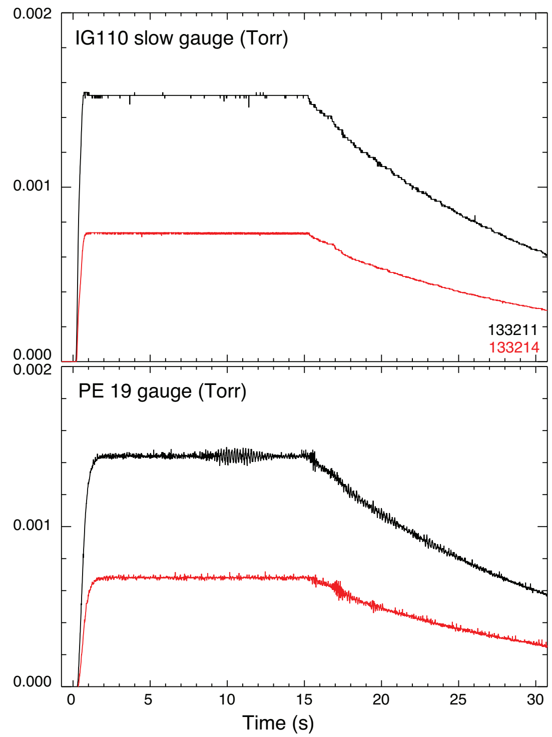


- SGI-U is operated at flow rates 50-250 Torr l /s ($3.5 – 17.5 \times 10^{21}$ s^{-1})
- Supersonic deuterium jet properties:
  - Jet divergence half-angle: 6^o - 25^o (measured)
  - Mach number $M = 4$ (measured)
  - Estimated: T ~ 60 - 160 K, $n < 5 \times 10^{23}$ m^{-3}, v_{flow} = 2.4 km/s, v_{therm} ~ 1.1 km/s
  - Nozzle $Re = 6000$

SGI fueling results in higher fueling efficiency, lower edge neutral pressure

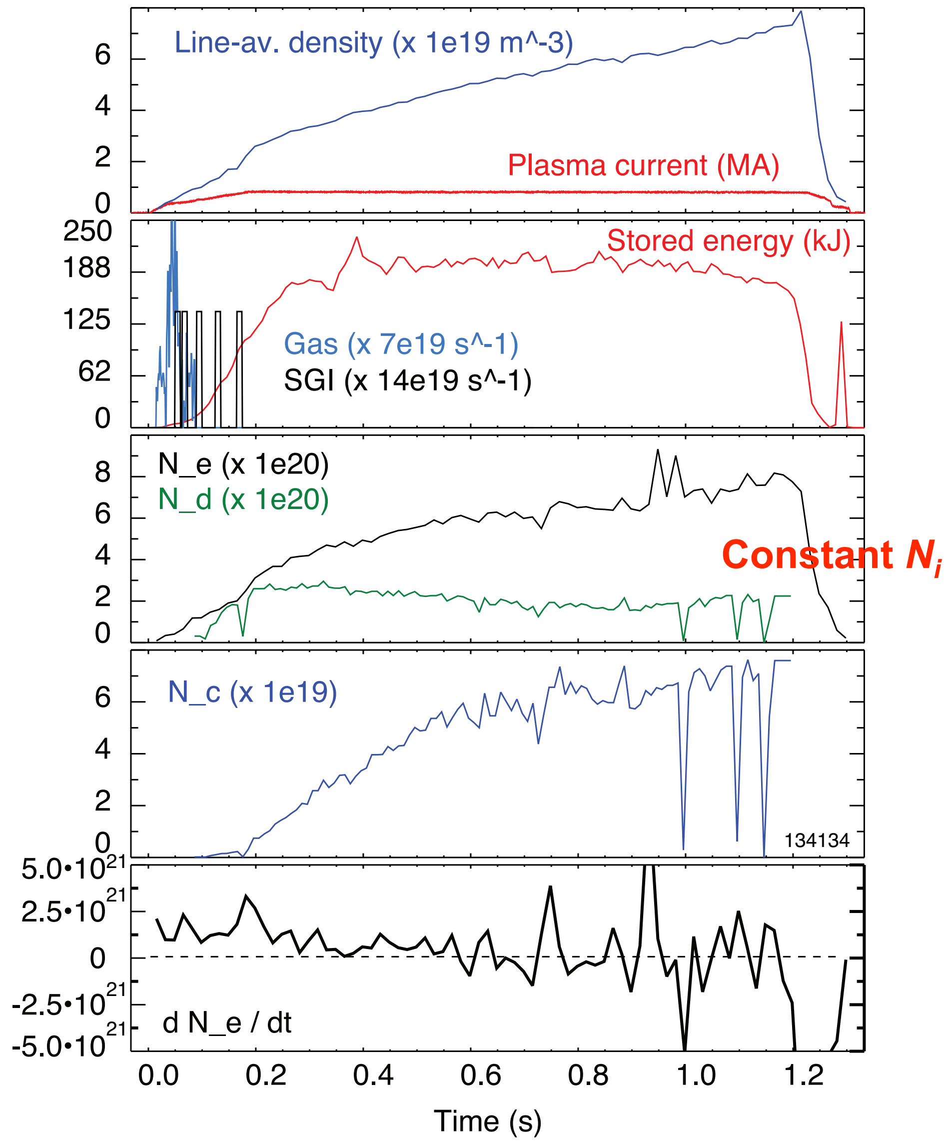


- Comparison between **SGI** and **conv. gas injection** was only possible by 1) matching density in 1 MA, 6-4 MW discharges; 2) comparing gas injection rate and total gas inventory



SGI-only fueling scenario with steady-state ion inventory developed

- Obtained good n_e and T_e profiles (at outer gap ~ 10 cm) to compare SGI and LFS fueling
  - Will analyze pedestal height and width in collaboration with ORNL
- Developed shoulder and SGI long pulse fueling scenarios
- Developed SGI-only fueling scenario with ion density control
  - N_i constant, while N_e is rising due to carbon; LITER at 9 mg/min



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XP 924 – "Snowflake" divertor in NSTX

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Acknowledgements: E. Kolemen, D. Gates, R. Bell, S. Gerhardt, R. Kaita, H. W. Kugel, B. LeBlanc, J. E. Menard, A. L. Roquemore (PPPL), J.-W. Ahn, A. McLean, R. Maingi (ORNL), R. Maqueda (Nova Photonics), R. Raman (U.Washington), and the NSTX Research Team

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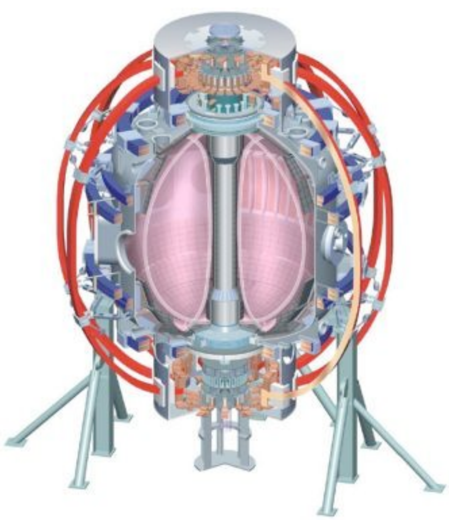

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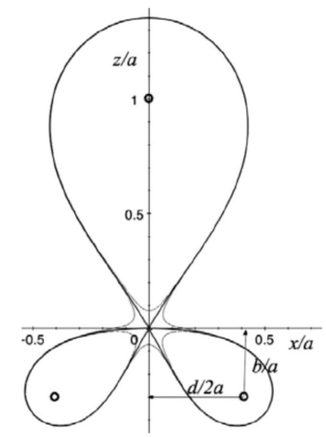
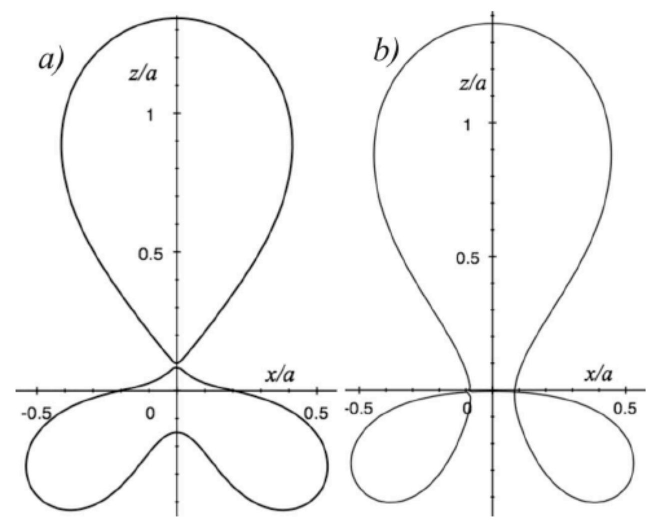
"Snowflake" divertor configuration: theory predicts many edge physics benefits

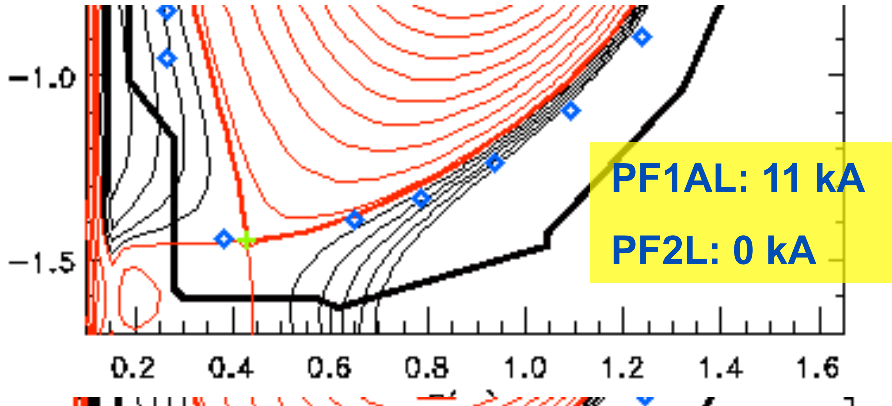
- "Snowflake" divertor (SFD) configuration proposed and theoretically studied by D. D. Ryutov (LLNL) (Phys. Plasmas 14, 064502 (2007); Phys. Plasmas, **15, 092501 (2008),** paper IC/P4-8 at IAEA FEC 2008)
- SFD obtained by creating a second-order poloidal null
- Two cases – SFD-plus and SFD-minus
- Predicted properties
  - Large flux expansion ($\boldsymbol{B_p/B}$ small)
    - Divertor peak heat flux reduction
  - SOL flux tube squeezing – barrier for turbulence
  - Possibility of ELM control (different magn. shear)
  - Enhanced X-point ion loss (?)



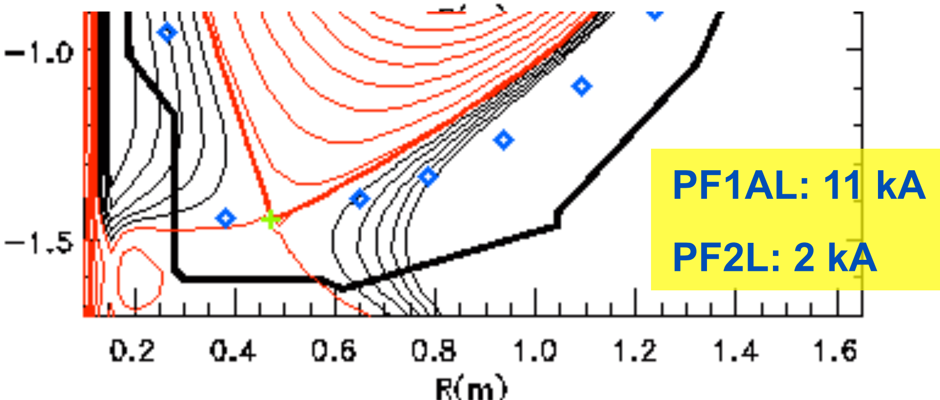


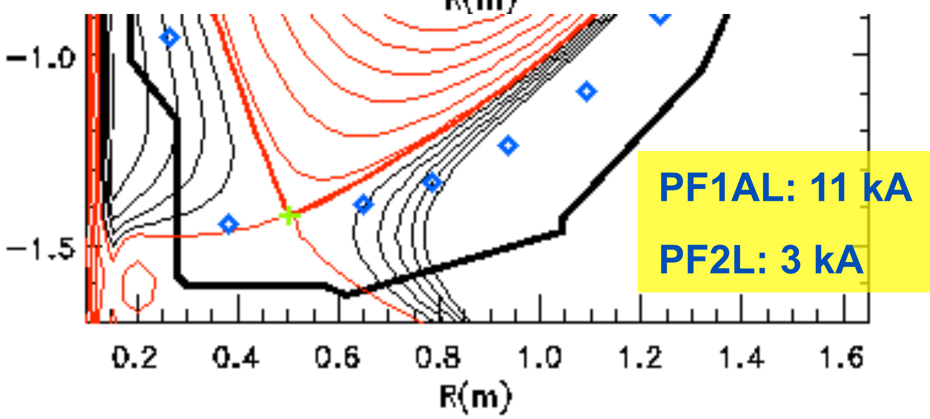
SFD-plus and SFD-minus

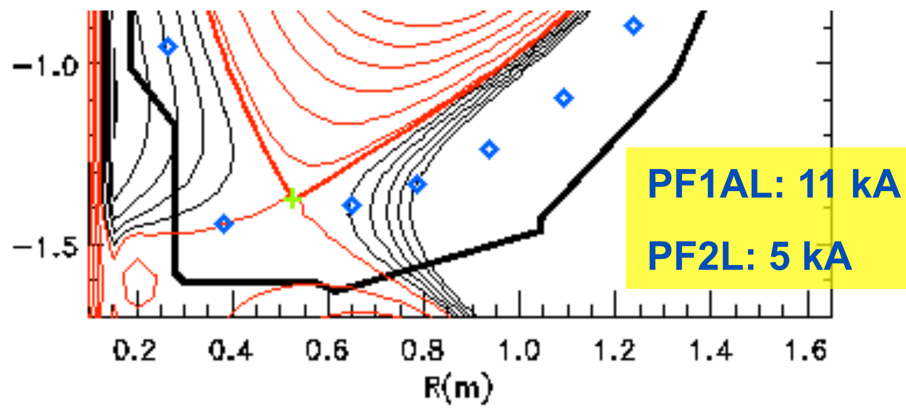
ISOLVER code was used to study configuration trends *vs* divertor coil currents



- ISOLVER - predictive free-boundary axisymmetric equilibrium solver (J. E. Menard)
  - ☑ normalized pressure and current profiles and boundary shape as input
  - ☑ matches a specified plasma current and β,
  - ☑ computes coil currents as output

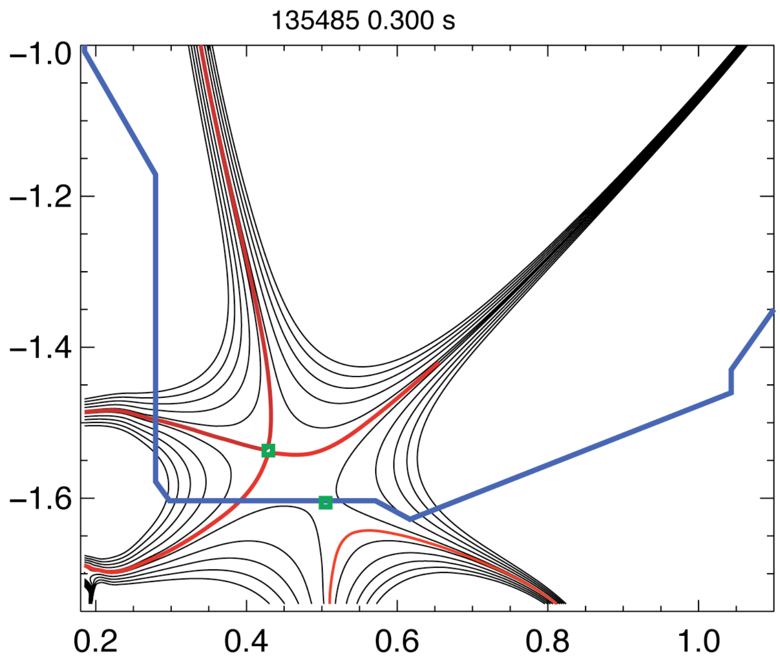


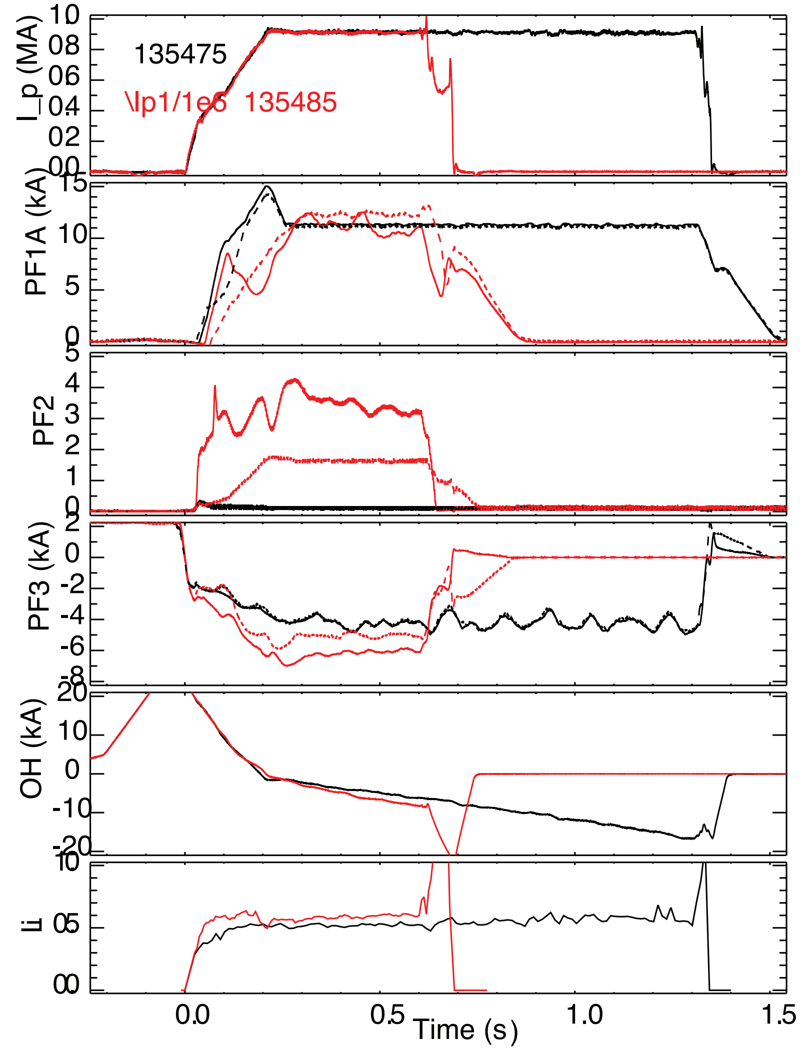




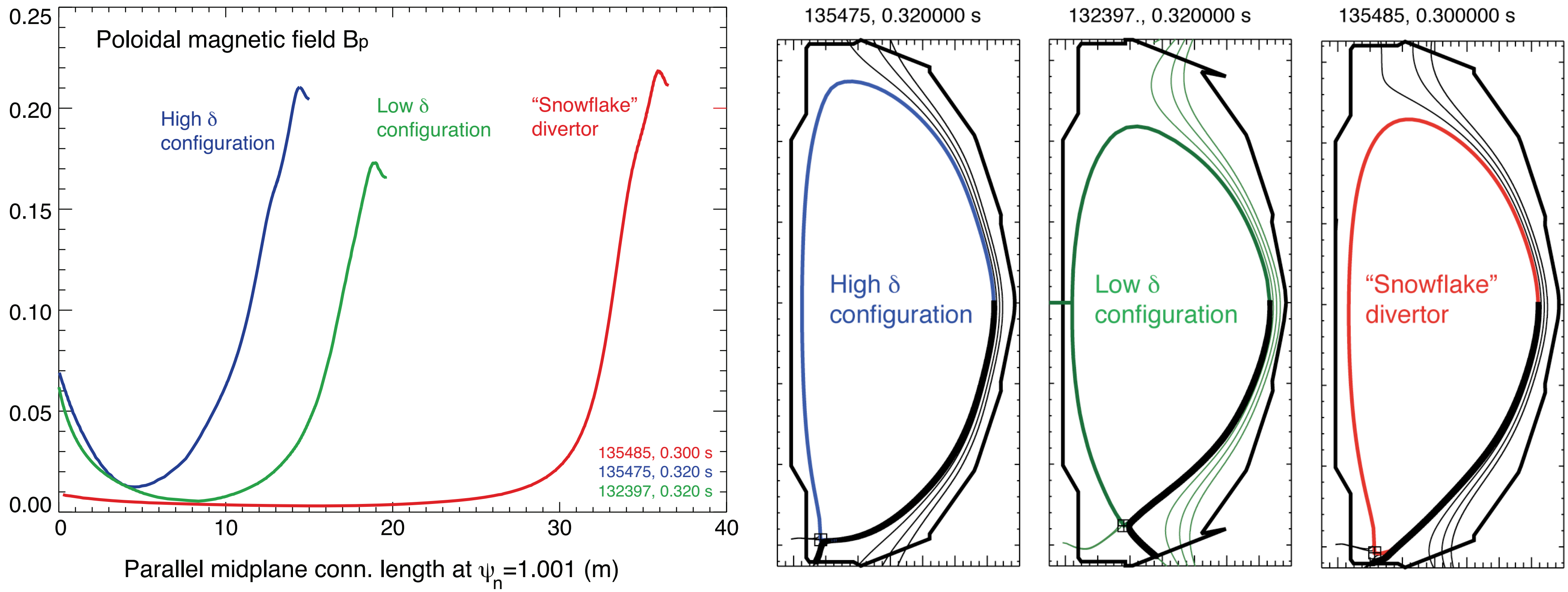
XP 924 demonstrated steady-state "snowflake" divertor configurations

- Only got ½ run day
- Used PCS strike point (SP) control on both inner and outer SPs
- Scanned OSP between 0.44 to 0.69 m
- Best SFD was obtained with R_{OSP} ~ 0.55 m





SFD has highest flux expansion at strike point and longest connection length



Configuration	Flux expansion	L_x (m)	L_{tot} (m)
SFD	68.1	16.3	36.5
Low δ	4.3	8.4	19.6
High δ	10.0	4.5	15.0

Divertor data analysis of "snowflake" configurations is in progress…

- Divertor heat flux