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Boundary Physics Topical Science Group summary

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NSTX FY 2010 Results Review

30 September 2010

Princeton, NJ

Culham Sci Ctr
U St. Andrews
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U Quebec

Boundary Physics TSG priorities are defined by

- **DOE and NSTX Milestones**
  - **FY2010 DOE Joint Research Target:** Conduct experiments on major fusion facilities to improve understanding of the **heat transport in the tokamak scrape-off layer** (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER.
  - **FY2010 Research Milestone R(10-3):** Assess H-mode **pedestal characteristics and ELM stability** as a function of collisionality and lithium conditioning
  - **FY2011 DOE Joint Research Target:** Conduct experiments on major fusion facilities to improve the understanding of the physics mechanisms responsible for the **structure of the pedestal** and compare with the predictive models described in the companion theory milestone.
- **NSTX-U planning needs and ST development path needs**
- **ITPA participation, ITER needs**

Three Boundary Physics TSG priorities have been defined for FY 2010 run

- Compare divertor heat flux widths to midplane density and temperature widths and edge turbulence characteristics, and determine the scaling of SOL and divertor heat transport (**FY2010 Joint Research Milestone**)

- Determine the relationship of ELM properties to discharge boundary shape, lithium conditioning, and 3D resonant magnetic perturbations (RMPs), and compare stability of pedestal / ELMs with model calculations (**Milestone R10-3**)

- Understand and develop a predictive capability for the physics mechanisms responsible for the structure of the H-mode pedestal (**FY2011 Joint Research Milestone**)

FY 2010 BP TSG Experiments are supporting 3 APS DPP Invited talks and 4 IAEA FEC presentations

- APS Invited Talks:
  - J.-W. Ahn, Modification of divertor heat and particle flux profiles with 3-D fields in NSTX
  - J. Canik, Edge transport and turbulence reduction, and formation of ultra-wide pedestals with lithium coated PFCs in NSTX
  - V. A. Soukhanovskii, Taming the Plasma Material Interface with the ``Snowflake'' Divertor in NSTX

- IAEA FEC presentations:
  - J. Canik, Oral, Optimization of Density and Radiated Power Evolution Control using Magnetic ELM Pace-making in NSTX
  - R. Maingi, Oral, Modification of Edge Profiles, Edge Transport, and ELM Stability with Lithium in NSTX
  - V. A. Soukhanovskii, Poster, Synergy between the “Snowflake” Divertor Configuration and Lithium Plasma-Facing Component Coatings in NSTX
  - J.-W. Ahn, Poster, Divertor heat and particle flux profile modification during 3-D field application in NSTX

Completed and remaining experiments address high-priority issues for STs, NSTX-U and ITER

- Completed experiments
  - XP 1026, A. Loarte, Effects of ELM control with resonant magnetic perturbation on edge power fluxes between and at ELMs
  - XP 1043, R. Maingi, Scaling of heat flux profiles and edge turbulence in NSTX discharges with lithium-coated PFCs for the FY2010 JRT
  - XP 1044, A. Diallo, Increasing the Range of Achievable Pedestal Height
  - XP 1045, V. A. Soukhanovskii, "Snowflake" divertor configuration
  - XP 1046, J.-W. Ahn, Effect of externally applied 3D fields on divertor profiles
  - XP 1048, J.-K. Park, RMP threshold of ELM modification at different q_{95}
  - XP 1051, S. Zweben, Test of LLD Electrodes for SOL Control
  - XP 1069, J. Canik, Watching ELMs disappear with optimum diagnosis of turbulence
- Remaining (scheduled) experiments
  - XP 1030, D. Battaglia, ELM suppression using 3D fields from a single row off-midplane coils on NSTX
  - XP 1050, V. A. Soukhanovskii, Radiative divertor with impurity seeding and lithium pumping
  - XP 1068, R. Goldston, Edge harmonic oscillations
  - XP J. Boedo, SOL transport and turbulence with lithium conditioning

XP 1026 (A. Loarte): Effects of ELM control with RMP on edge power fluxes between and at ELMs

XP1026: Completed for effect of 3-D field on ELMy divertor profiles in plasma regime of ITER's interest

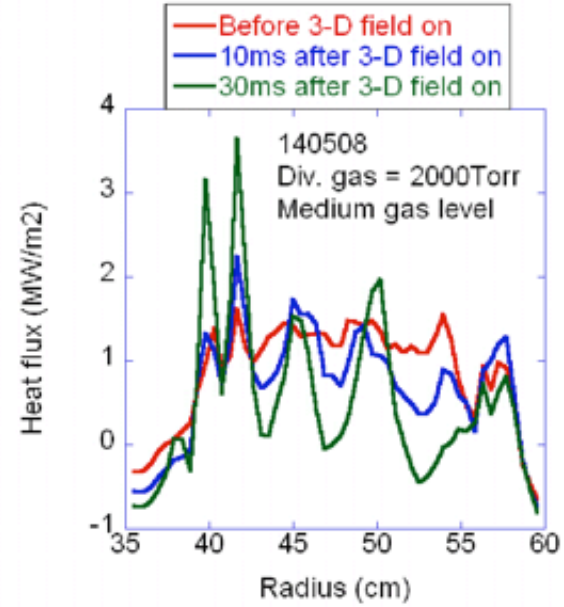
- Divertor plasma collisionality scan:

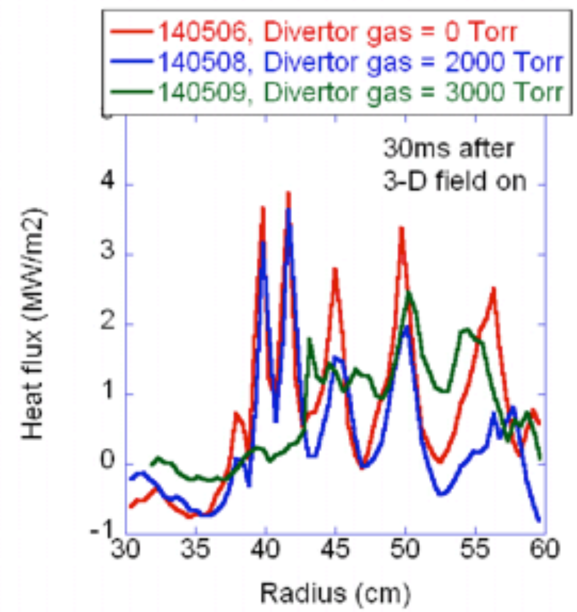
  Gas puffing scan from Bay E GIS successfully varied divertor plasma collisionality in lithium environment

- 3-D field applied to small ELM plasmas in different divertor regimes: Confirmed different effect on inter-ELM divertor profiles, ELM data analysis in progress

- Ip and pedestal collisionality scan:

  Two Ip and three ped. collisionality points obtained. Data analysis in progress





XP 1043 (R. Maingi): Scaling of heat flux profiles and edge turbulence in NSTX discharges with lithium-coated PFCs for the FY 2010 JRT

FY2010 JRT on SOL heat transport included analysis of data, development of two-color IR camera, and modeling

- Data analyzed from old XPs: 434, 814, 816, 923 (no lithium)
  - Good I_p, P_{NBI}, flux expansion scans
  - Mix of low and high triangularity discharges
  - Presented at PSI and IAEA (T.K. Gray)
- Two-color IR camera technique developed (A.G. McLean)
  - Presented at RSI conference
- Comprehensive dataset obtained with two-color camera
  - Mostly high triangularity discharges, two lithium rates
- Modeling done with SOLT code (Myra) and XGC-0 with neoclassical transport (Park, Pankin, Chang)
- Oct. 2010 4Q report nearing completion

Complete dataset obtained with 300 mg lithium evaporated between discharges

- Goal 1: measure SOL heat flux footprint at high δ
  - ✓NBI scan: 2-6 MW in 1 MW increments at 1.2, 0.8 MA
  - ✓I_p scan 0.7 – 1.3 MA at 4 MW and B_t=0.45 T
  - ✓B_t scan from 0.33-0.55 T at 0.8 MA, 4 MW
  - ✓Made a great dataset for τ_E scaling analysis
- Goal 2: measure heat flux footprint in C-Mod/DIII-D low κ, near-DN shape
  - ○ *Got I_p between 0.72-0.8 MA, few NBI levels*
- Goal 3: measure heat flux footprint as a function of δ_r^{sep}
  - ✓High δ: got data at δ_r^{sep}= 0, -2.5, -5, -7.5, -1 cm
  - ○ *Low δ: got data at δ_r^{sep}= -0.7, -1.3 cm*
- *Camera timing and multiple resets complicating analysis*

Very nice dataset obtained with 150 mg lithium evaporated between discharges after camera reset problem resolved

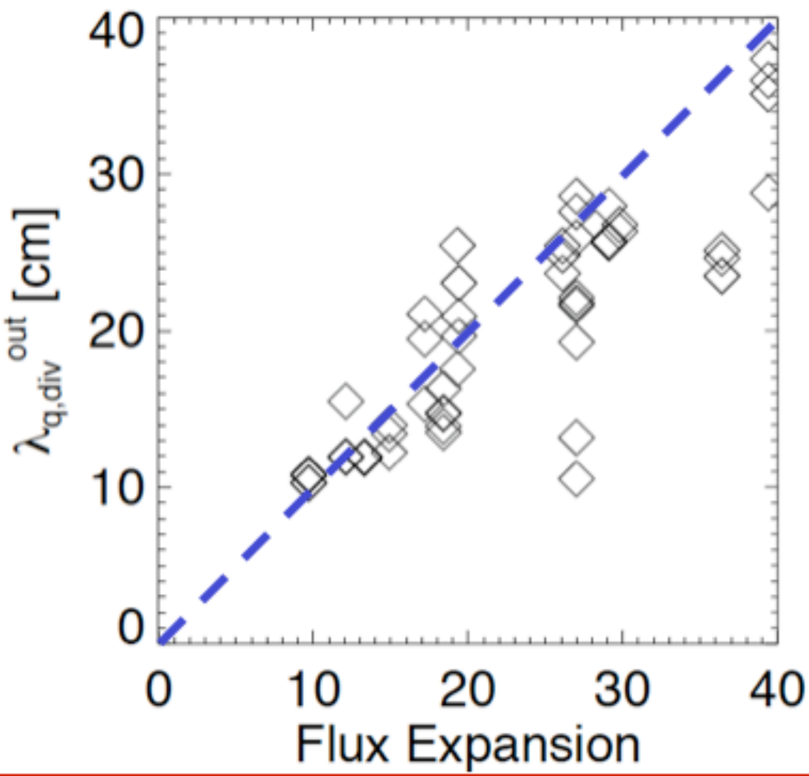
- Goal 1: measure SOL heat flux footprint at high δ
  - ✓I_p scan 0.7 – 1.3 MA at 4 MW and B_t=0.45 T
  - ✓B_t scan 0.35, 0.45, 0.55 T at 0.8 MA, 4 MW
  - ✓Some comparison between 3 and 4 MW discharges
- Goal 2: measure heat flux footprint in C-Mod/DIII-D low κ, near-DN shape
  - ✓Got I_p at 0.75 MA, 2 & 3 MW comparison
- Goal 3: measure heat flux footprint as a function of δ_r^{sep}
  - ✓High δ: got good data at δ_r^{sep}= 0 and (-20)mm
- *Analysis in progress with existing 1-D calculation*
  - Implementation of 2-D calculation, and appropriate frame averaging will be implemented during down time

Analysis of existing NSTX data highlighted important empirical dependences

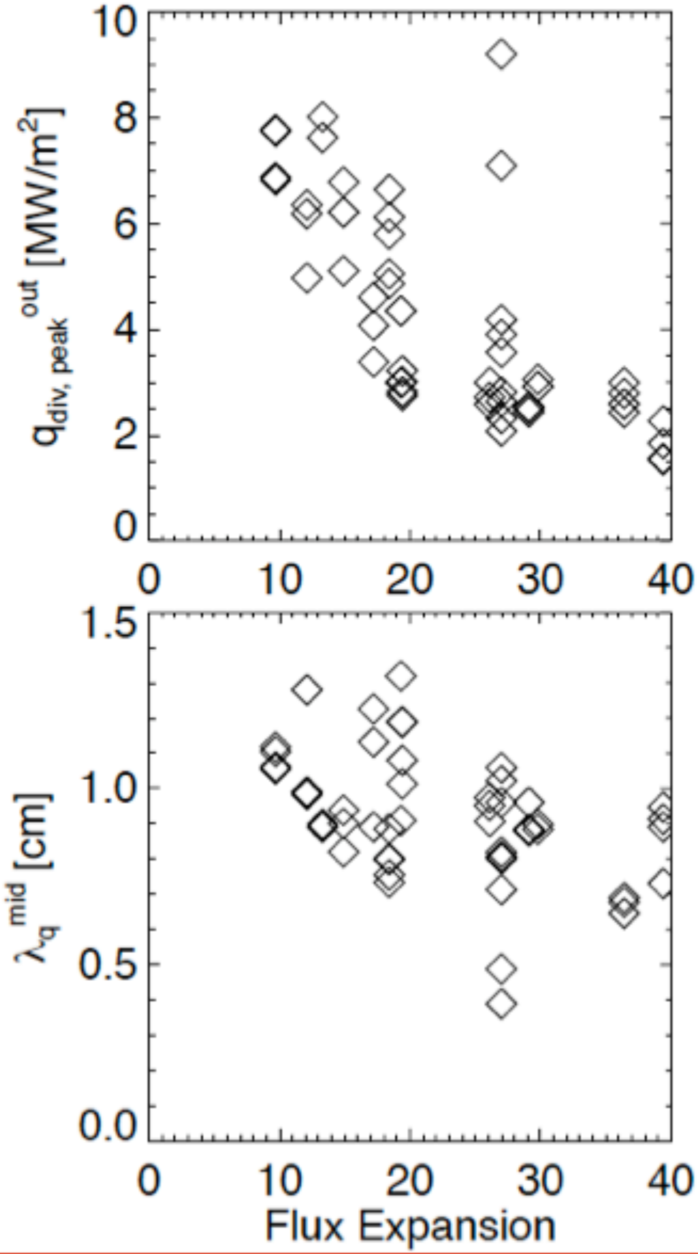
- Divertor heat flux footprint width mapped to midplane (λ_q^{mid}) decreases rapidly with I_p
- λ_q^{mid} independent of P_{SOL} in low radiated power regimes, and contracts very weakly with flux expansion
  - Means high flux expansion, from e.g. snowflake or reduced X-point height, can be used to spread the heat flux in the divertor
- λ_q^{mid} projected at 3 mm for NSTX-Upgrade, with $q_{peak} \sim 24$ MW/m^2 with flux expansion = 30
  - Have not projected to NSTX-U based on "snowflake" yet

Peak heat flux decreases inversely with flux expansion with roughly constant λ_q^{mid} in NSTX

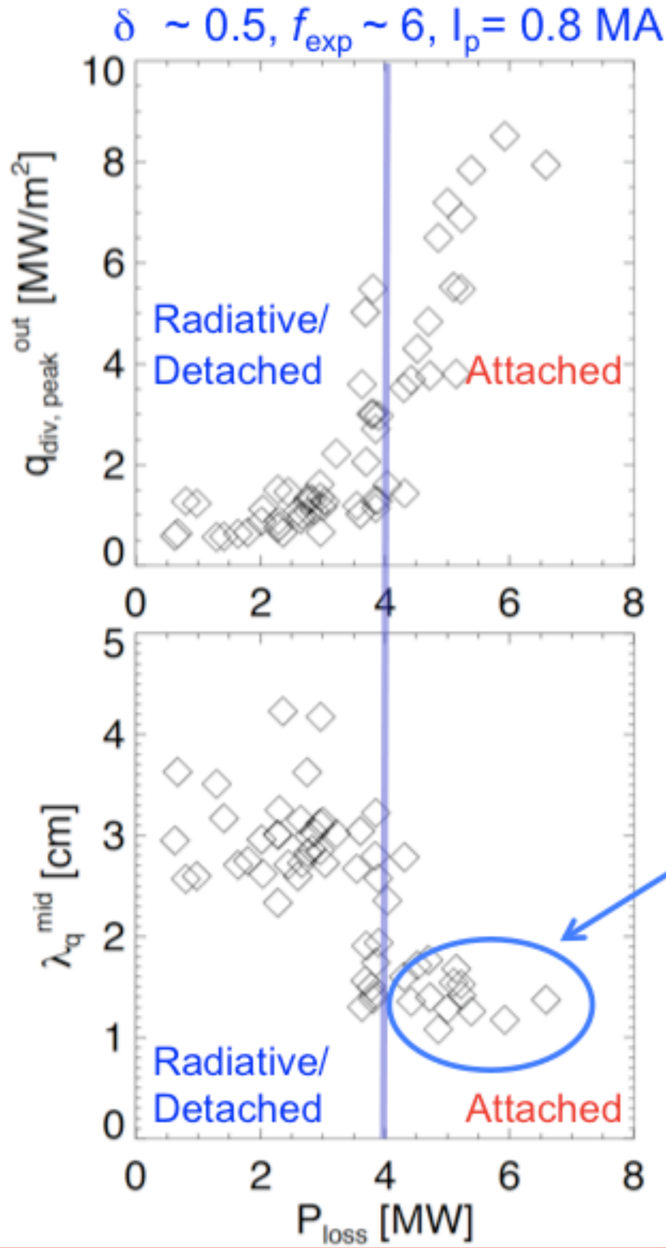
- λ_q^{div} increases with flux expansion
- λ_q^{mid} stays approximately constant during the scan



Gray, PSI10



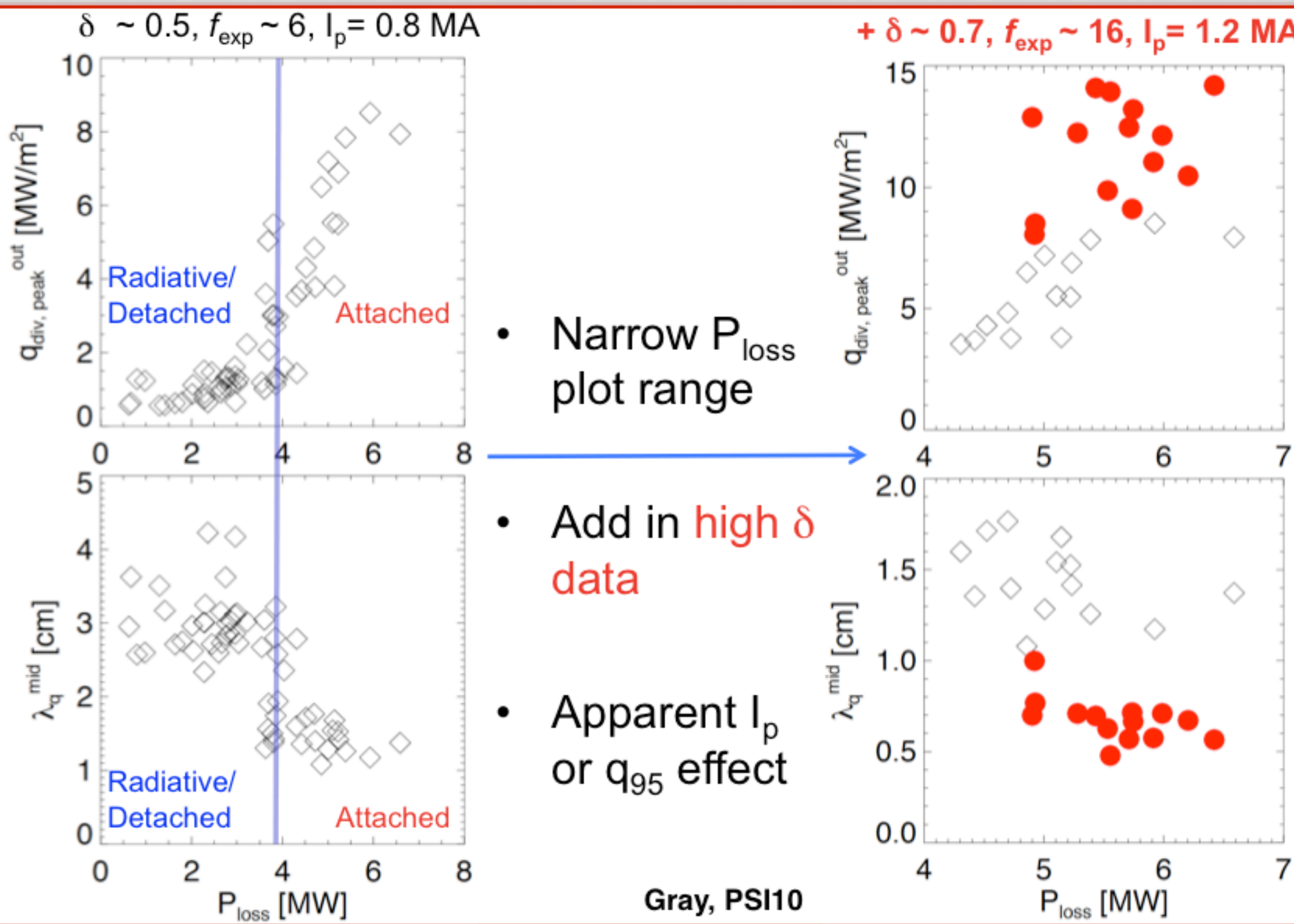
Heat flux width λ_q^{mid} largely independent of P_{loss} in attached plasmas in NSTX



- Peak divertor heat flux increases with P_{loss}
- Apparent change in slope near P_{loss}=4 MW in these conditions, as divertor transitions from a radiative/ detached divertor to an attached divertor
- λ_q^{mid} relatively independent of P_{loss} in high heat flux regime
- All data in this talk averaged over ELMs and before lithium coatings

Gray, PSI10

Heat flux width λ_q^{mid} largely independent of P_{loss} in attached plasmas in NSTX

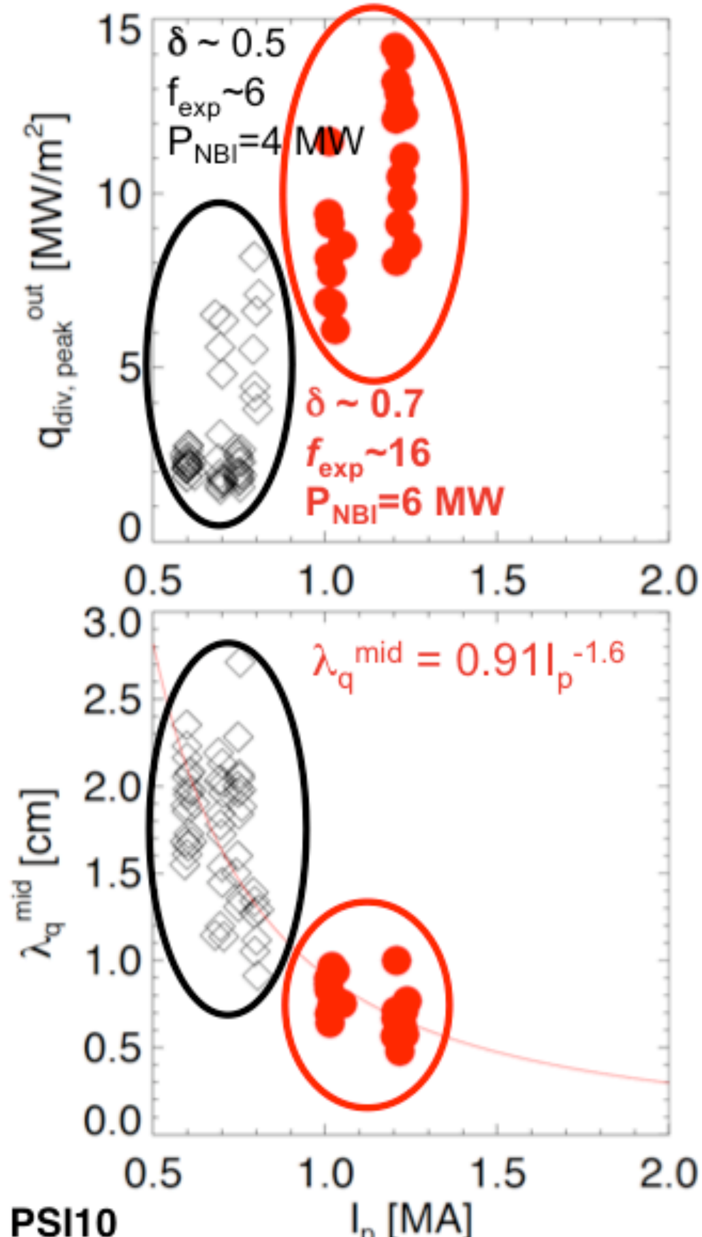


- Narrow P_{loss} plot range
- Add in high δ data
- Apparent I_p or q_{95} effect

Gray, PSI10

Heat flux width decreases strongly with I_p in NSTX

- Combined data from dedicated I_p scans in low δ and high δ discharges
  - I_p dependence also in DIII-D, JET
  - Different P_{NBI} and f_{exp}, but previous slides shows no P_{loss} or f_{exp} effect on λ_q^{mid}
  - q_{95}, $\ell_{||}$ different
- Power law fit: λ_q^{mid} ~ 3 +/- 0.5 mm @ 2 MA



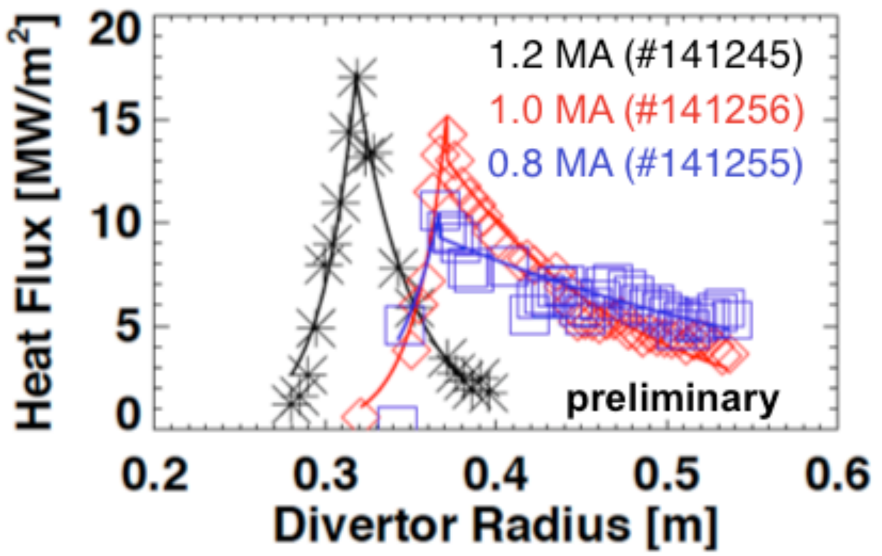
Gray, PSI10

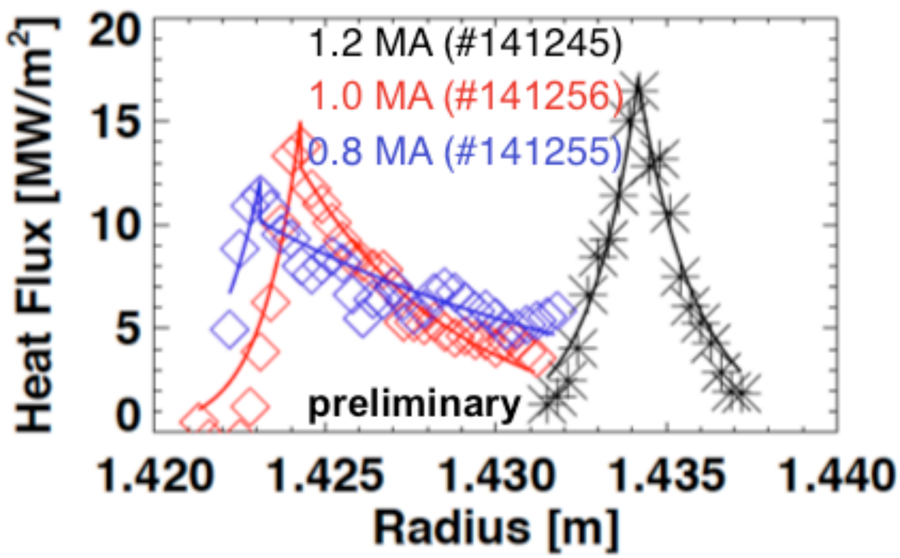
New data with lithium confirms main dependences in the absence of lithium

- Divertor heat flux footprint width contracts with I_p
- λ_q^{mid} independent of P_{SOL} in low radiated power regimes, and independent of B_t
- λ_q^{mid} decreases by ~ 50% in ELM-free discharges enabled through lithium conditioning (analysis in progress)
- Analysis of δ_r^{sep} dependence in progress also

Strong inverse I_p dependence of SOL widths observed in discharges with lithium wall coatings

- Outer divertor peak heat flux increases with I_p, because both λ_q^{div} and λ_q^{mid} contract
  - Data from 150 mg lithium
  - Consistent with no lithium results
  - Qualitatively consistent with 300 mg lithium results

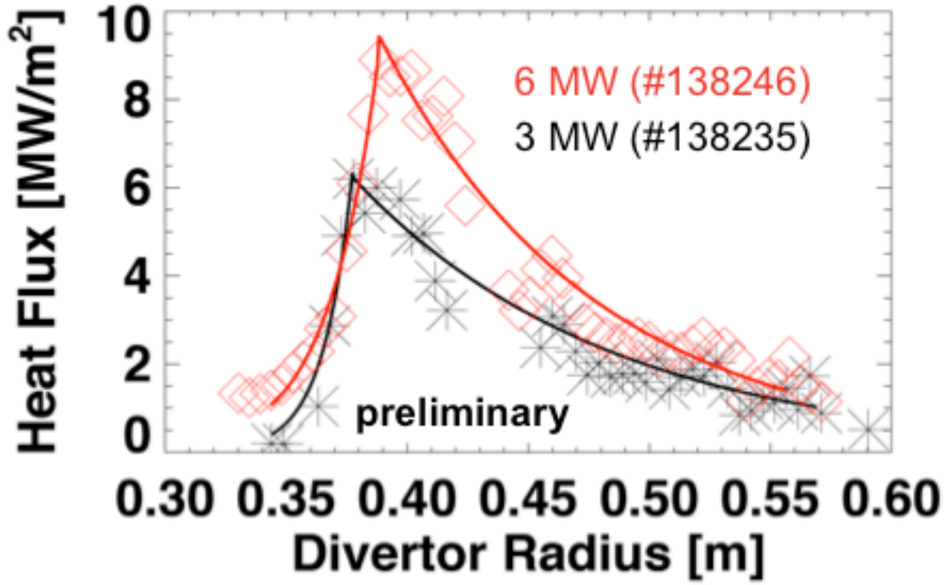




- *Intensity calibration preliminary!*

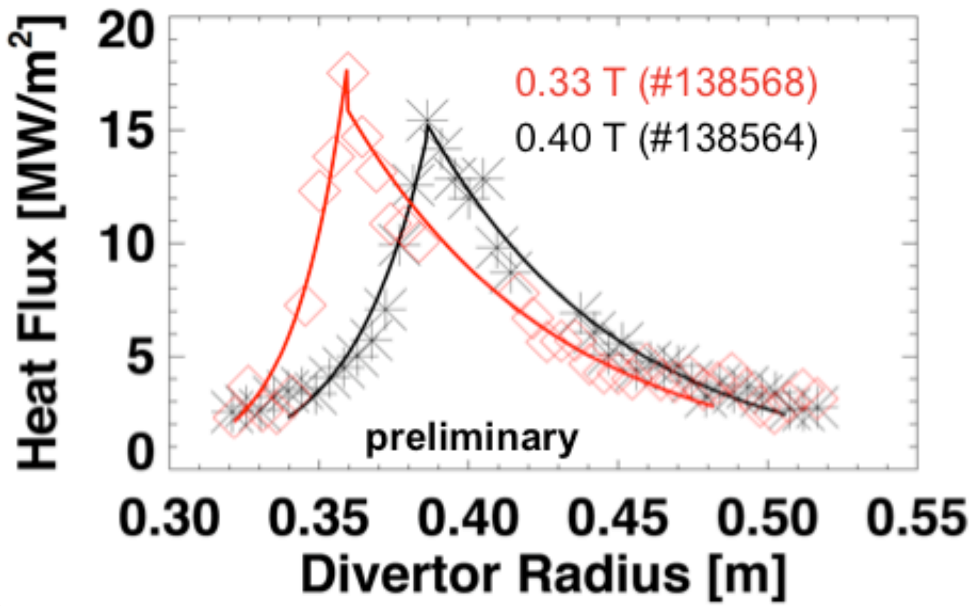
SOL width independent of P_{SOL} and B_t

- Outer divertor peak heat flux increases with NBI power, but λ_q^{div} and λ_q^{mid} stay constant
  - Consistent with no lithium results



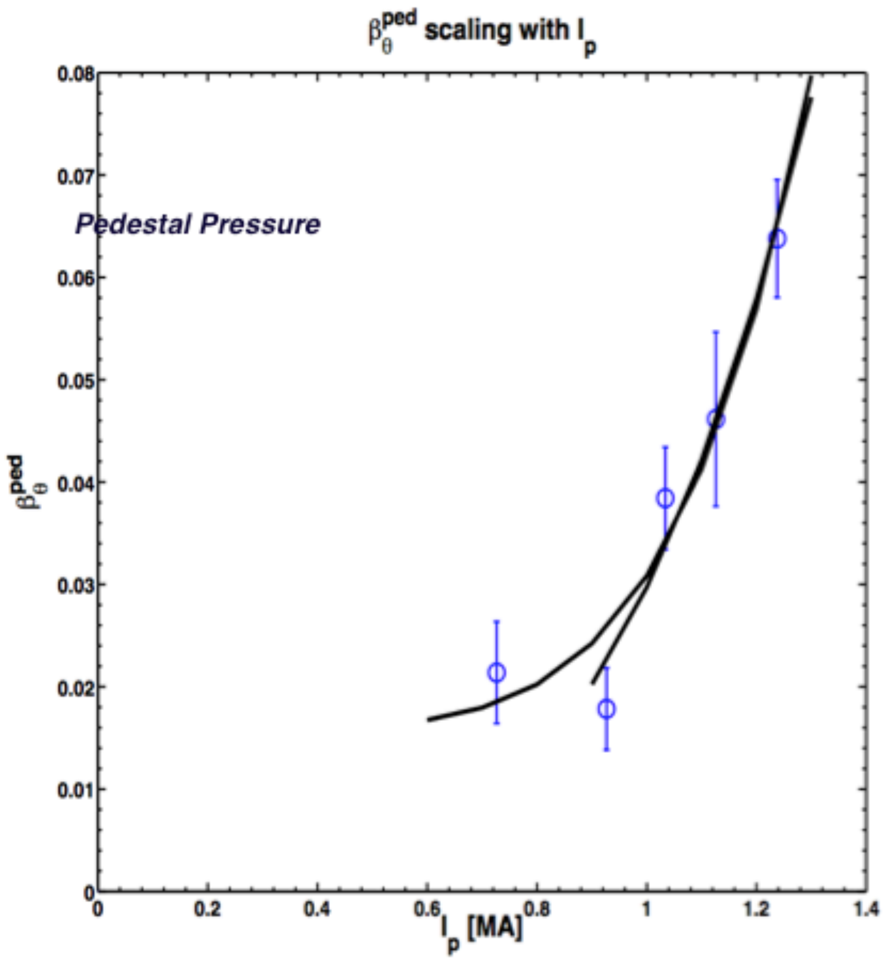
- Outer divertor peak heat flux, λ_q^{div} and λ_q^{mid} insensitive to B_t

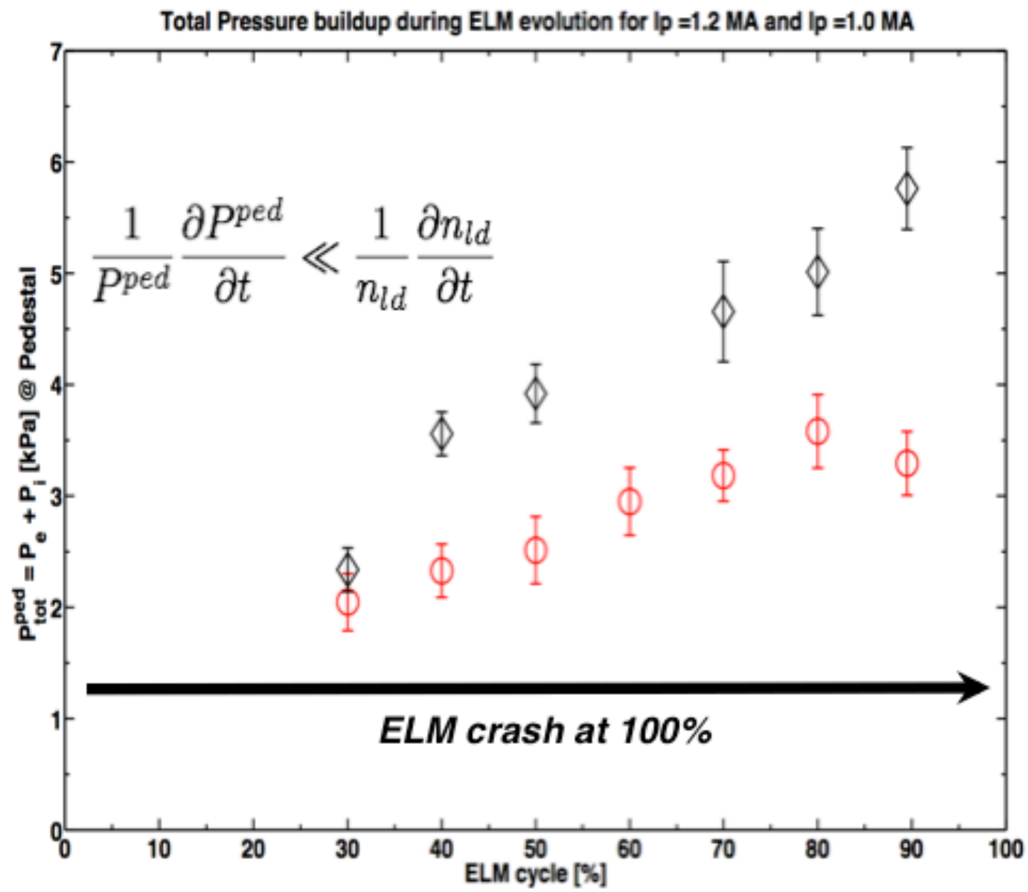
- *Intensity calibration preliminary!*



XP 1044 (A. Diallo): Increasing the Range of Achievable Pedestal Height

Pedestal β_{pol} increases with I_p, and pedestal pressure gradient does not always saturate before ELM crash





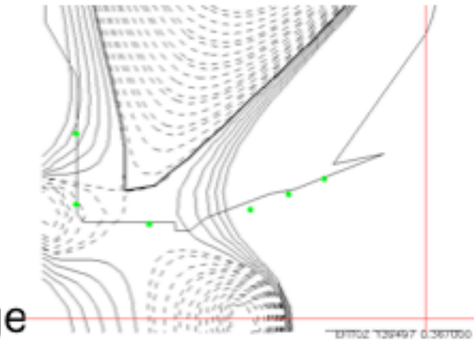
- Pedestal pressure increases with a variation by a factor ~ 3 before the ELM crash showing **no consistent sign of saturation at high plasma current**
- Strong I_p scaling with the pedestal β_{pol} consistent with ITER98 scaling

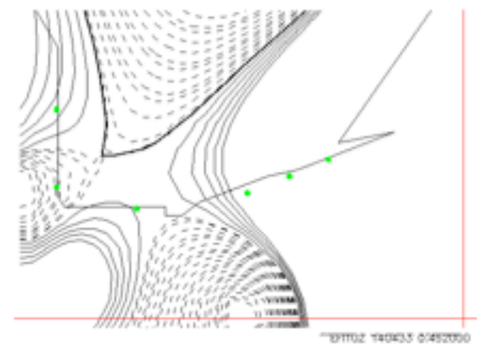
Diallo, APS 2010

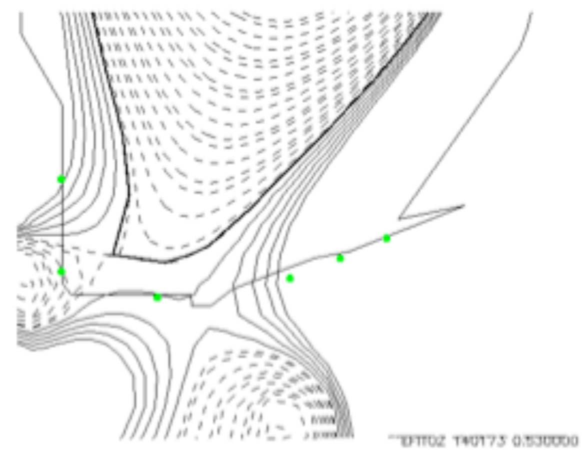
XP 1045 (V. A. Soukhanovskii): "Snowflake" divertor configuration in NSTX

Steady-state snowflake divertor configurations were developed and characterized in XP 1045

- Magnetic configuration development in FY2010
  - **Two-coil SFD** configuration with PCS SP control in medium-δ discharges
    - ✓ Much improved control of SPs and SFD, but periods of SFD for 100-200 ms
  - **SFD with three coils** (w/ reversed PF1B) from a **medium-δ** discharge
    - ✓ Steady-state SFD, however, all shots were ELMy, despite I_p=0.8-1 MA, P_{in}=3-6 MW
  - **SFD with three coils** (w/ reversed PF1B) from a from a **high-δ** discharge
    - ✓ Best steady-state SFD, no OSP sweeping through CHI gap
    - ✓ Fiducial like-performance, basis for integration with advanced scenarios
  - Developing **X-divertor** with reversed PF1B and high X-point

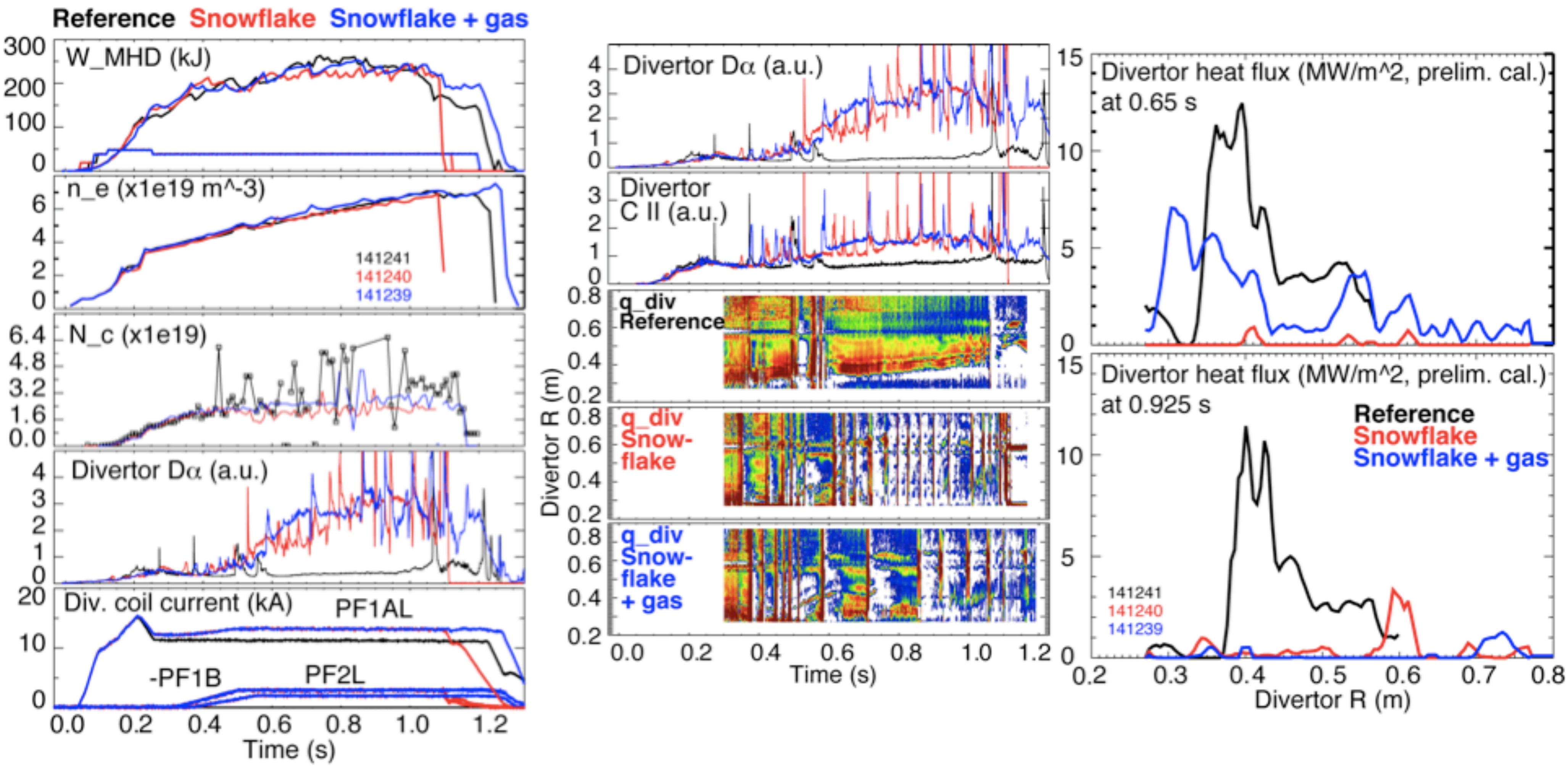






- Characterization
  - Confirmed partial detachment of OSP
  - Confirmed heat flux reduction in SFD
  - Could not confirm impurity reduction due to ELMs

Snowflake divertor configuration nearly eliminated steady-state heat load on divertor PFCs

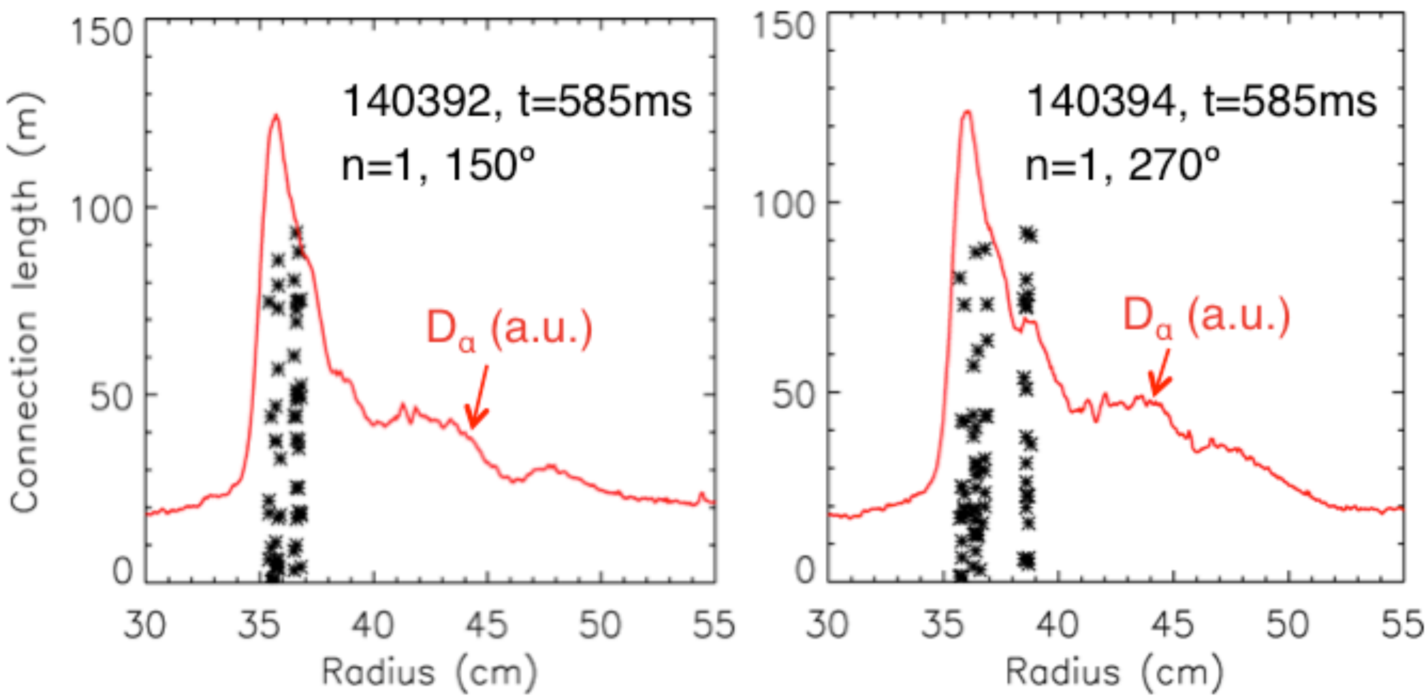


- Heat load due to ELMs remained

XP 1046 (J.-W. Ahn): Effect of externally applied 3D fields on divertor profiles

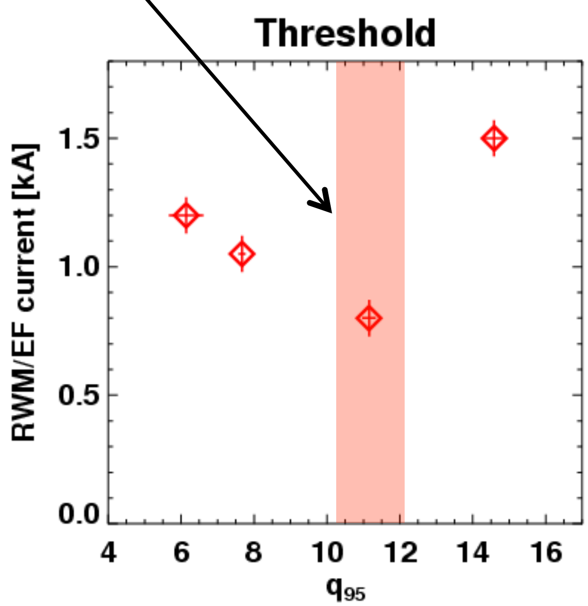
XP1046: Completed parameter scan for effect of 3-D field on ELM-free divertor profiles

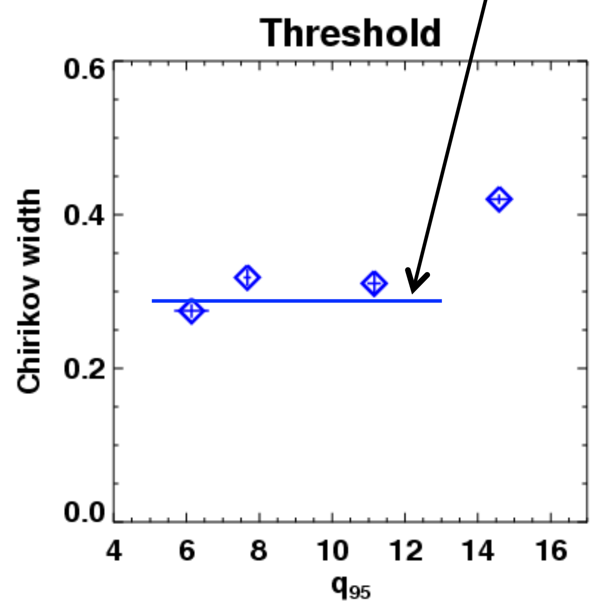
- q95 scan: Divertor profiles show finer striations with higher q95, in good agreement with vacuum field line tracing
- n=1 phase scan: Asymmetric divertor footprints confirmed and good agreement with field line tracing
- Pedestal collisionality scan: Data analysis in progress



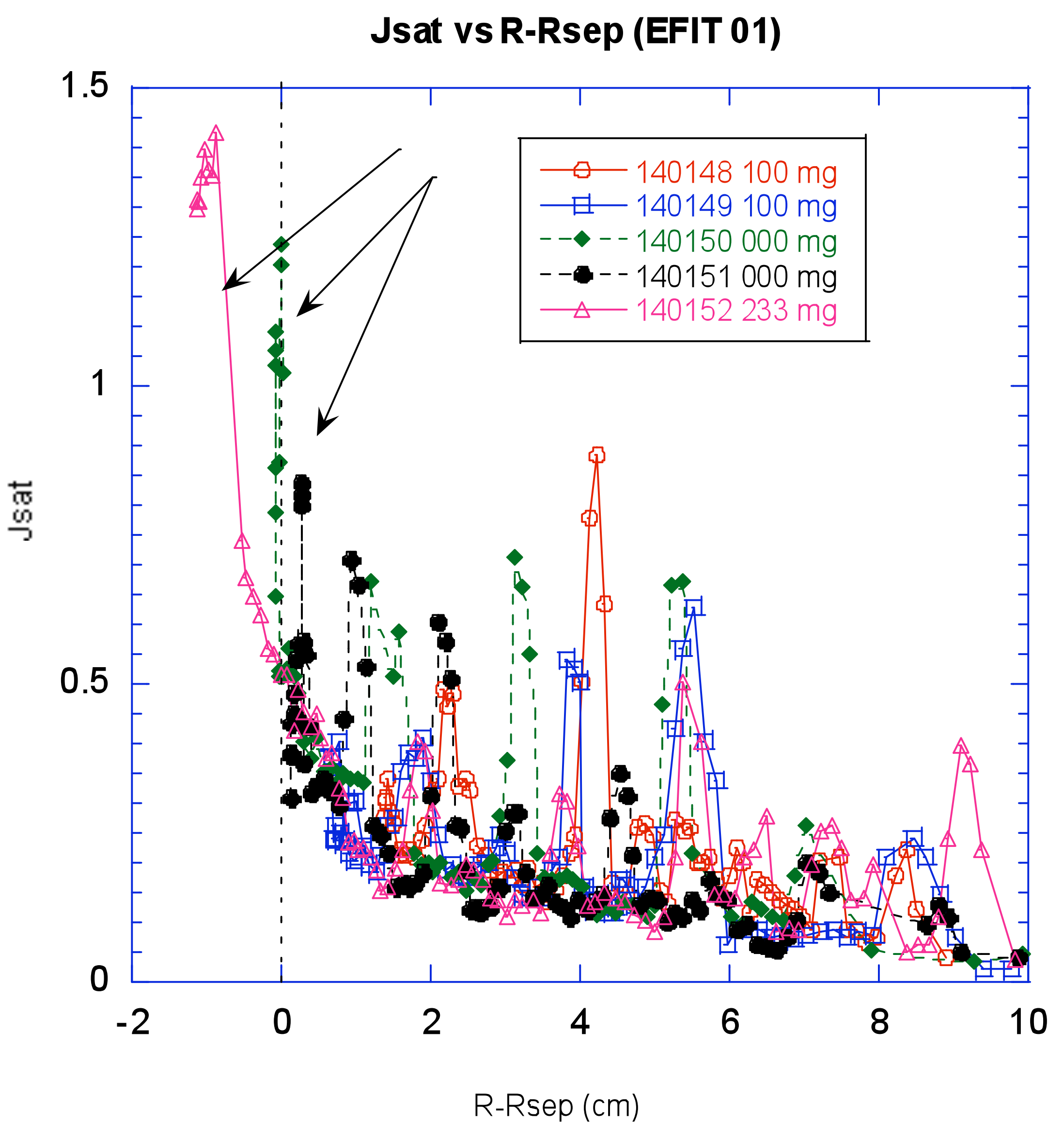
XP 1048 (J.-K. Park): RMP threshold of ELM modification at different q_{95}

- Target plasmas : I_P=0.7~1.3MA, 3MW beam, 300mg LITER, high κ~2.5, high σ~0.8, q_{95}=6~15
- For q_{95}=6~11 : Lower threshold for higher q_{95}, stochastic layer (vacuum Chirikov > 1) width ~ 0.3
- For q_{95}>12 : Higher threshold for higher q_{95}
- Optimal q-window ~ 11 for ELM triggering?





XP (J. Boedo): SOL profiles almost identical, Pedestal shows differences as lithium rate changed

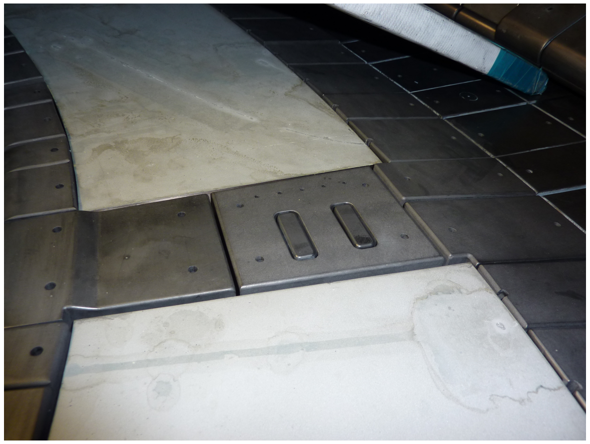


- Data shows NO/LITTLE difference (aside small ELMs) in the SOL
- Only difference seems to be where the pedestal rises near R-Rsep=0
- In 140152 (233 mg li) the pedestal is~0.5-1 cm further in
- In 140150 and 140151 (0 ms lithium) the rise is closer to the nominal R-Rsep=0
- We conclude that the transport changes occur inside, or at, the LCFS.

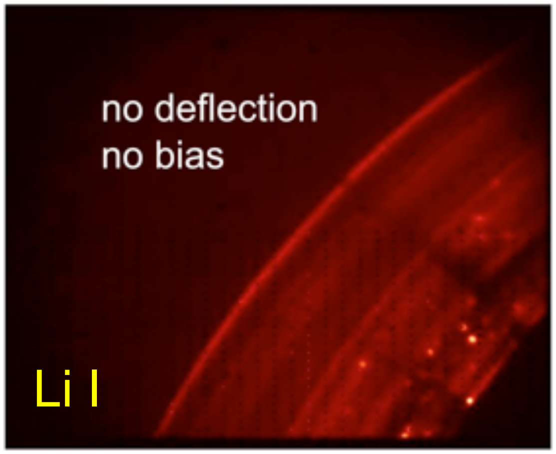
XP 1051 (Zweben): Effect of divertor electrode biasing on local SOL transport

- Motivation: learn whether the divertor plate particle flux can be controlled by local electrode biasing
- Goal of XP: bias electrodes in Bays E and K and measure effects on local probes and visible emission
- Electrodes deflect plasma at divertor surface by ~ 1 cm

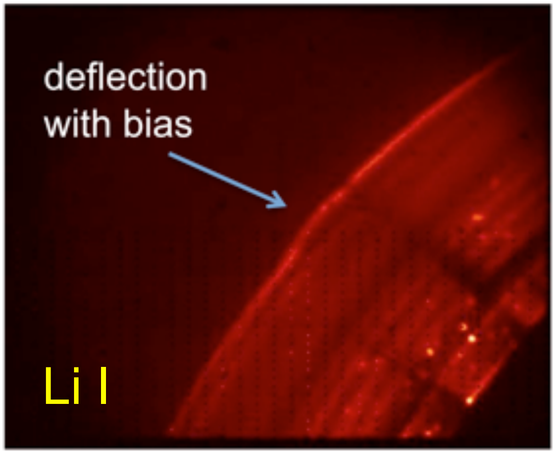
Bay E electrodes



without ±90 V bias



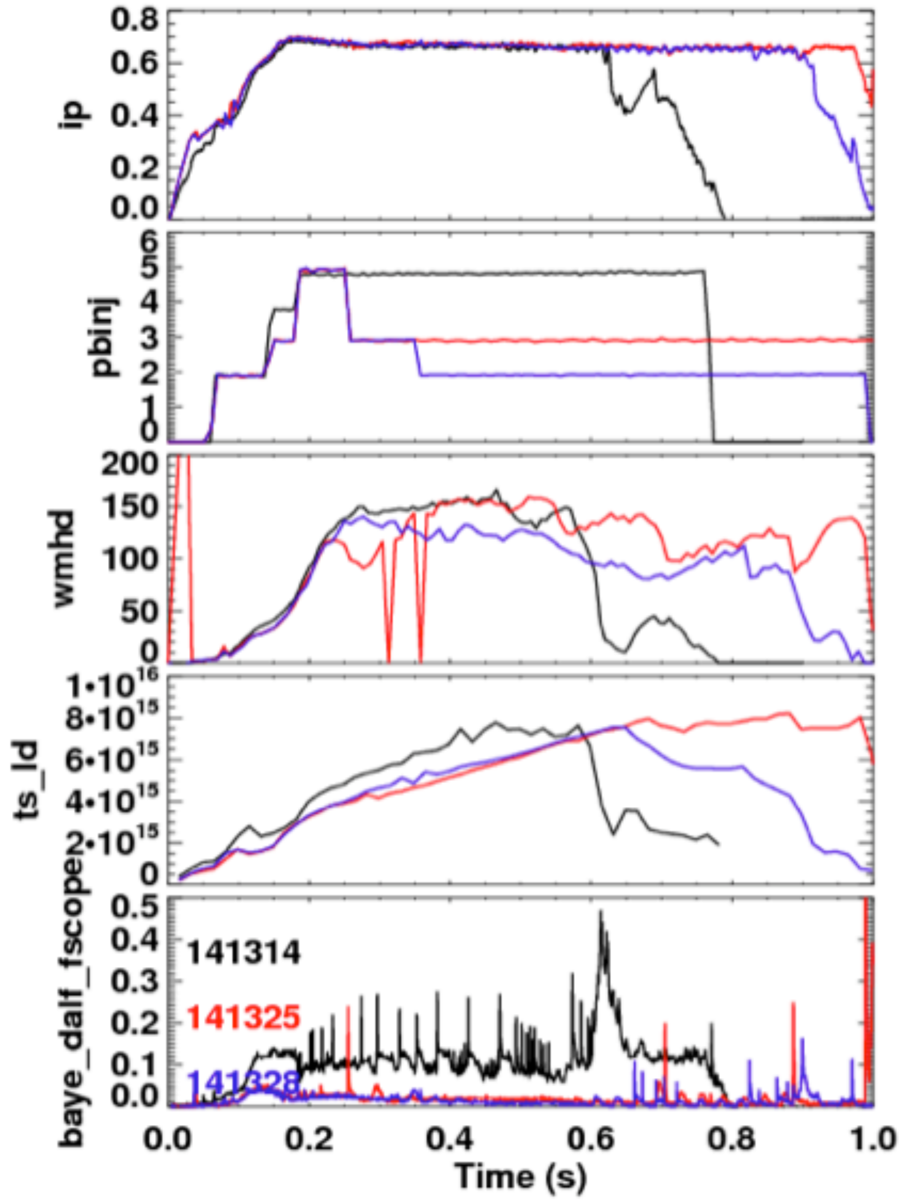
with ±90 V bias



XP 1069, J. Canik, Watching ELMs disappear with optimum diagnosis of turbulence

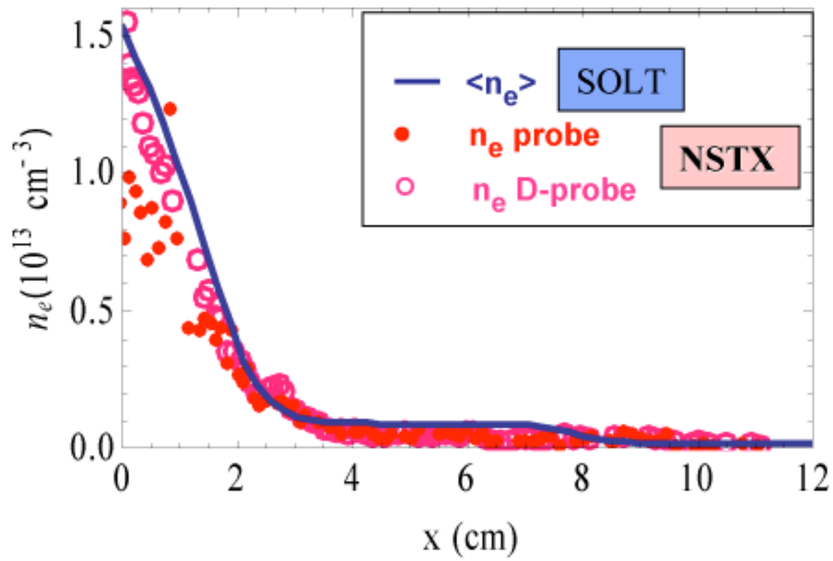
XP 1069: Watching ELMs disappear with optimum turbulence diagnosis

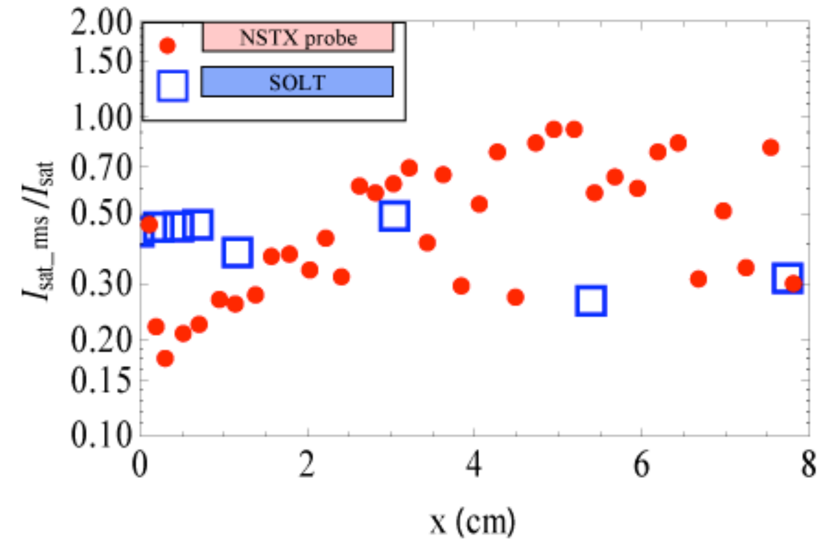
- Goal: measure edge turbulence as lithium is applied and pedestal profiles modified
- Transition from low-lithium evaporation to high repeated for low-delta shape (~129015)
- Previous trends seen again as Li increased
  - Lower density
  - Same stored energy for less power
  - Reduced recycling, ELMs gone
- Turbulence data obtained with high-k, BES, reflectometers, GPI
  - Analysis underway



Modeling highlight: Lodestar SOLT Modeling for FY 2010 JRT Examines Role of Turbulence in SOL Width

- SOLT: 2-D fluid turbulence at midplane.
- Simulate several H-mode shots to investigate P_{in} & I_p scaling,
- Compare with GPI, probe, IRTV.
- See weak λ_q scaling with P_{in}; I_p scaling is weaker than observed.
- New convective cell mechanism determines width in H-mode simulations.





[Myra et al, FY 2010 4Q Report]