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Boundary Physics TS Group Summary

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NSTX FY2008 Mid-run Assessment Meeting

16 April 2008

Princeton, NJ

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAERI
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Boundary Physics TSG priorities are defined by

- **NSTX Milestones**
  - **Research Milestone R(08-3):** Study variation and control of heat flux in scrape-off layer
  - **Joule FY 2009 milestone** on particle control and retention
  - **Facility Milestone F(09-2):** Commission the liquid lithium divertor target for particle pumping (April 2009)
  - **Research Milestone R(10-3):** Assess H-mode pedestal characteristics and ELM stability as a function of collisionality and lithium conditioning (September 2010)
- **ITPA participation**
- **Coordinated research between Alcator C-Mod, DIII-D and NSTX**
- **ST development path needs, ITER needs**

Near-term milestones reflect high priority of SOL / divertor heat flux and lithium research on NSTX

- **NSTX FY 2008 Milestone (R08-3): Study variation and control of heat flux in SOL**

  The variation of the quasi-steady scrape-off layer (SOL) and divertor heat flux will be determined in NBI-heated H-mode plasmas in lower-single-null and double-null magnetic configurations over a range of plasma conditions. For controlling the divertor peak heat flux, the effectiveness of radiative and/or dissipative divertor regimes and their compatibility with high-performance, long-pulse H-mode plasmas will be assessed. Analytic and numerical SOL and divertor models will be used to distinguish the mechanisms responsible for setting the heat flux width, as well as heat flux reduction in the radiative and dissipative divertor regimes. This will establish a basis for projections of the SOL and divertor characteristics in the CTF and other future ST-based devices, and contribute to improving projections to ITER and future DEMO conditions

- **Joule FY 2009 Milestone on Particle control and retention**

  Conduct experiments on major fusion facilities to develop understanding of particle control and hydrogenic fuel retention in tokamaks. In FY09, FES will identify the fundamental processes governing particle balance by systematically investigating a combination of divertor geometries, particle exhaust capabilities, and wall materials. Alcator C-mod operates with high-Z metal walls, NSTX is pursuing the use of lithium surfaces in the divertor, and DIII-D continues operating with all graphite walls. Edge diagnostics measuring the heat and particle flux to walls and divertor surfaces, coupled with plasma profile data and material surface analysis, will provide input for validating simulation codes. The results achieved will be used to improve extrapolations to planned ITER operation.

NSTX participates in a number of high-level ITPA PEP and DSOL experiments

- **Pedestal and Edge Group (PEP)**
  - PEP-6 Pedestal structure and ELM stability in DN
  - PEP-9 NSTX/MAST/DIII-D pedestal similarity
  - PEP-16 C-MOD/NSTX/MAST small ELM regime comparison

- **Divertor and Scrape-Off Layer Group (DSOL)**
  - DSOL-15 Inter-machine comparison of blob characteristics
  - DSOL-17 Cross-machine comparison of pulse-by-pulse deposition

Coordinated Research thrusts between three US fusion facilities are consistent with NSTX priorities

- **Thrusts defined through discussions at National Tokamak Planning Workshop, September 17-19, 2007 at PSFC MIT**
  - **Particle balance and inventory studies**
  - **Edge localized mode (ELM) control, with emphasis on ELM suppression using resonant magnetic perturbations (RMP)**
  - **Scrape-off layer heat flux distribution physics**
  - **Plasma-material interaction (PMI) diagnostic development**

Two Boundary Physics TS Group priorities have been defined for FY 2008 run

- **Study variation and control of heat flux in SOL**
  - Characterize divertor heat flux and access to detachment (R08-3)
  - Compare divertor heat flux widths to midplane density and temperature widths and edge turbulence characteristics
- **ELMs and pedestal**
  - Determine relationship of ELM properties to discharge boundary shapes and lithium conditioning
  - Compare stability of pedestal and ELMs with model calculations

Four XPs contribute to SOL heat flux variation and control research on NSTX

- **XP 815 - J.-W. Ahn** - SOL width characterization - **1 day**
- **XP 816 - R. Maqueda** - Edge Characterization in high performance discharges - **1 day + 1 day**
- **XP 814 - V. A. Soukhanovskii** - Divertor detachment in highly-shaped plasmas - **1 day**
- **XP 806 - S. Zweben** - Edge Electrode Biasing for SOL Control - **1/2 day**

Legend: **Day allocated at Forum**

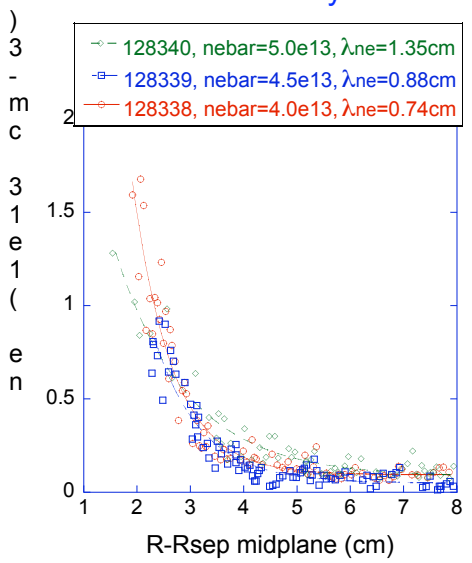
Suggested extra days

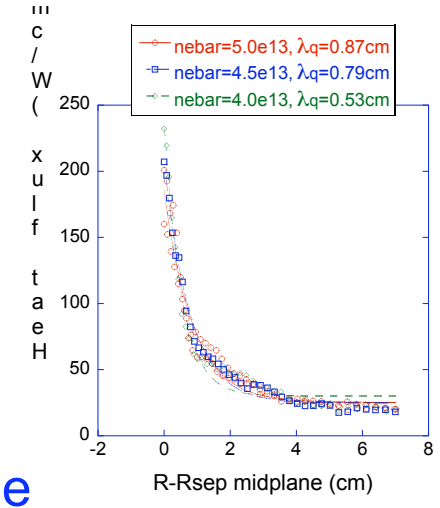
H-mode SOL width studies made good progress toward establishing scaling of λ_q with I_p, n_e, P_{in}

- **Motivation and Goals**
  - Relation between upstream SOL widths and target heat flux width as a function of I_p, n_e, P_{in}
  - SOL width scaling with I_p, n_e, P_{in}
  - Relation between edge turbulence characteristics and SOL widths
- **Status, Plans**
  - Confirmed trends of λ_q as a function of I_p (–), n_e (+), and P_{in} (–)
  - Confirmed trends of λ_{ne} in H-mode as a function of n_e (+)
  - Partially fulfilled necessary probe dataset for I_p and power scans (issues with separatrix positioning, access to low power H-mode, regime for decent probe data, etc), may need ~1/2 day to finish
  - Analysis of edge turbulence characteristics (probe Isat and GPI data) in relation with SOL widths under way

λ_{ne} and λ_q noticeably change with ~25% of n_e increase

H-mode density scan

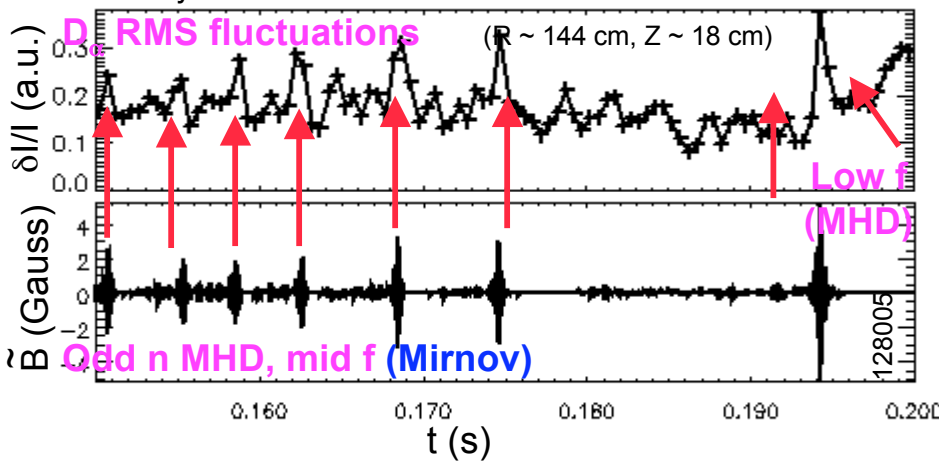




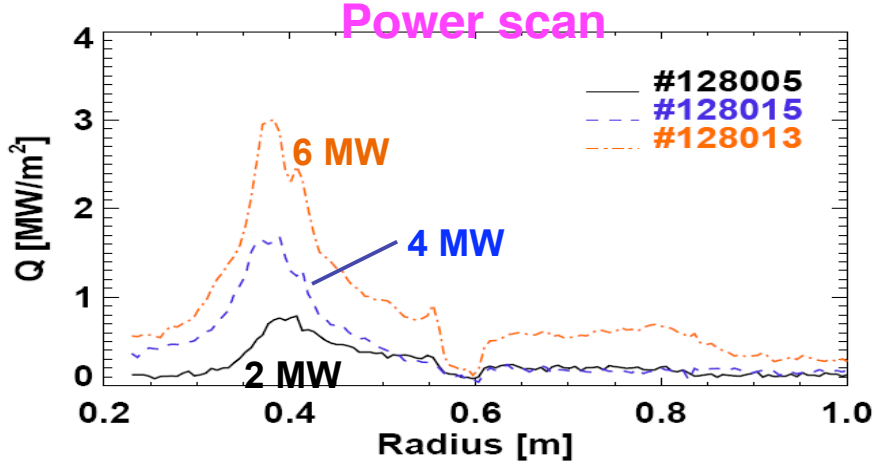
Edge characterization XP obtained important SOL and divertor data in high κ, δ configuration

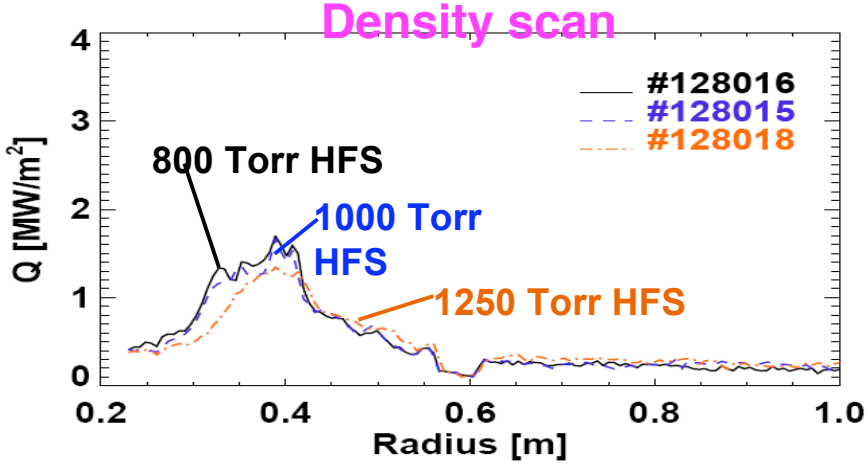
- **Goals:**
  - Characterize edge in plasmas with lowest divertor heat flux (high heat flux expansion)
  - Study divertor heat flux and radiation as function of NBI power (2, 4, and 6 MW, density (800, 1000 and 1250 Torr HFS), divertor flux expansion
  - Use discharges to study blob generation mechanisms during H-mode
- **Status: need 1/2 day to finish**

MHD bursts and irreproducible L-H transition complicate analysis of GPI turbulence/blob data



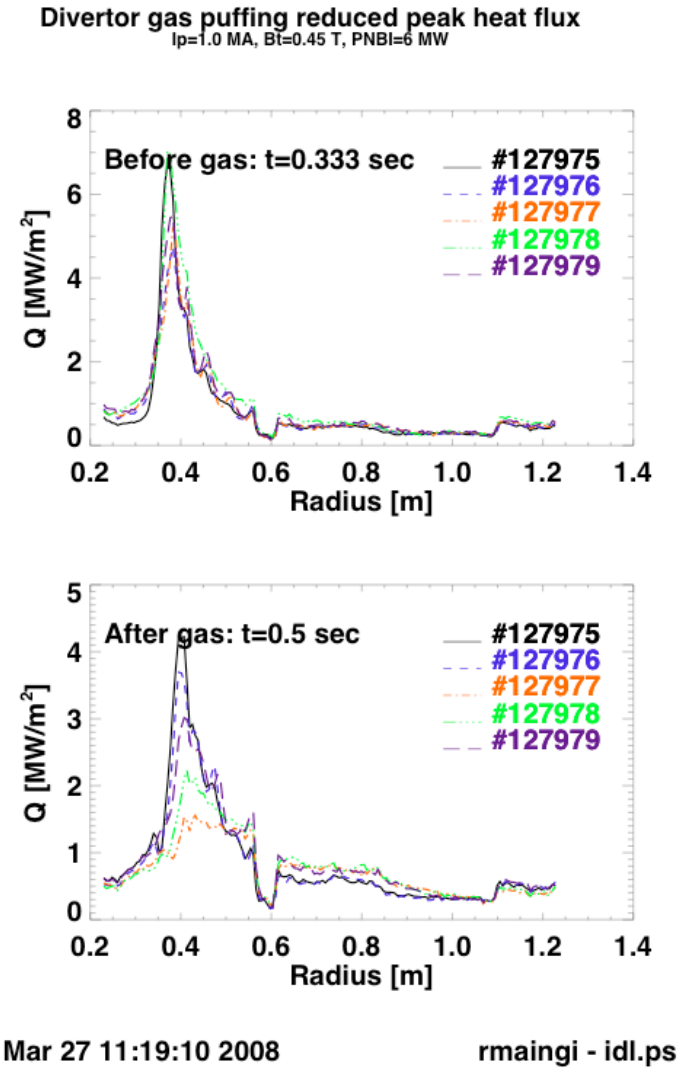
Divertor heat flux increased with NBI power but no change seen with density





Divertor detachment XP demonstrated 70 % peak heat flux reduction with radiative divertor

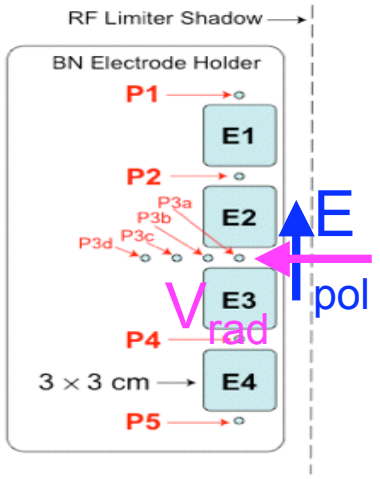
- **Goals:**
  - Obtain highly–shaped (κ = 2.2-2.3, δ = 0.65-0.75) **LSN** reference shot and reproduce **PDD conditions** at three I_p, P_{NBI} values **using D_2 injection**
  - Obtain highly–shaped **DN** reference sho and obtain PDD conditions **using D_2 injection** at three I_p, P_{NBI} values using various gas injection rates
  - Obtain highly–shaped **LSN** reference sh and obtain PDD conditions **using He injection**
- **Status:**
  - Obtained q reduction and detachment ir MA, 6 MW 4.5 kG discharges
  - Need 1/2 day to finish

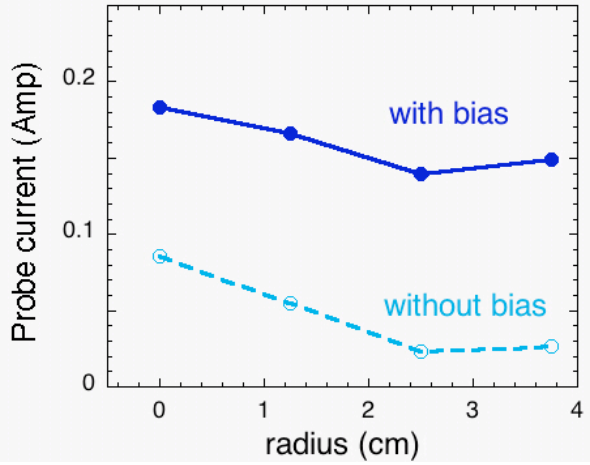


Changes in SOL width were produced using biasing with BEaP

- **Goals:**
  - Broaden SOL with local $V_{rad} = E_{pol} \times B$ using biased electrodes
  - Understand penetration of electric fields parallel and perp. to ***B***
- **Status:**
  - SOL broadened with ±90 volts between electrodes E2 &E3
  - SOL broadened with bias in L- and H-mode, Ohmic, RF
  - Electric field penetrates ≤ 1 m along B and a few cm ⊥ B
  - So far only done in far-SOL (shadow of RF antenna)

⇒ **can extend results to divertor strike region with small electrodes mounted in diagnostic section of LLD**





ELMs and pedestal research in NSTX in FY 2008 includes 5 XPs

- **XP 721 - A. Hubbard, R. Maingi, H. Meyer** - Comparison of Small ELM Regimes in Alcator C-MOD, MAST, and NSTX (ITPA PEP-16) - **0.5 day**
- **XP 609 - H. Meyer, R. Maingi** - Dependence of ELMs and Power Balance on Magnetic Balance and Fueling (ITPA PEP-6) - **0.5 day**
- **XP 809 J. Canik** XP on ELM control with RMP - **0.5 day**
- **R. Maingi, A. Kirk, T. Osborne** - Dependence of pedestal structure on aspect ratio (PEP 9) - **0.5 day**
- **D. K. Mansfield** - Initial Use of Dual LITER for ELMs Mitigation and Evaporator Characterization - **1 day + 0.5 day**

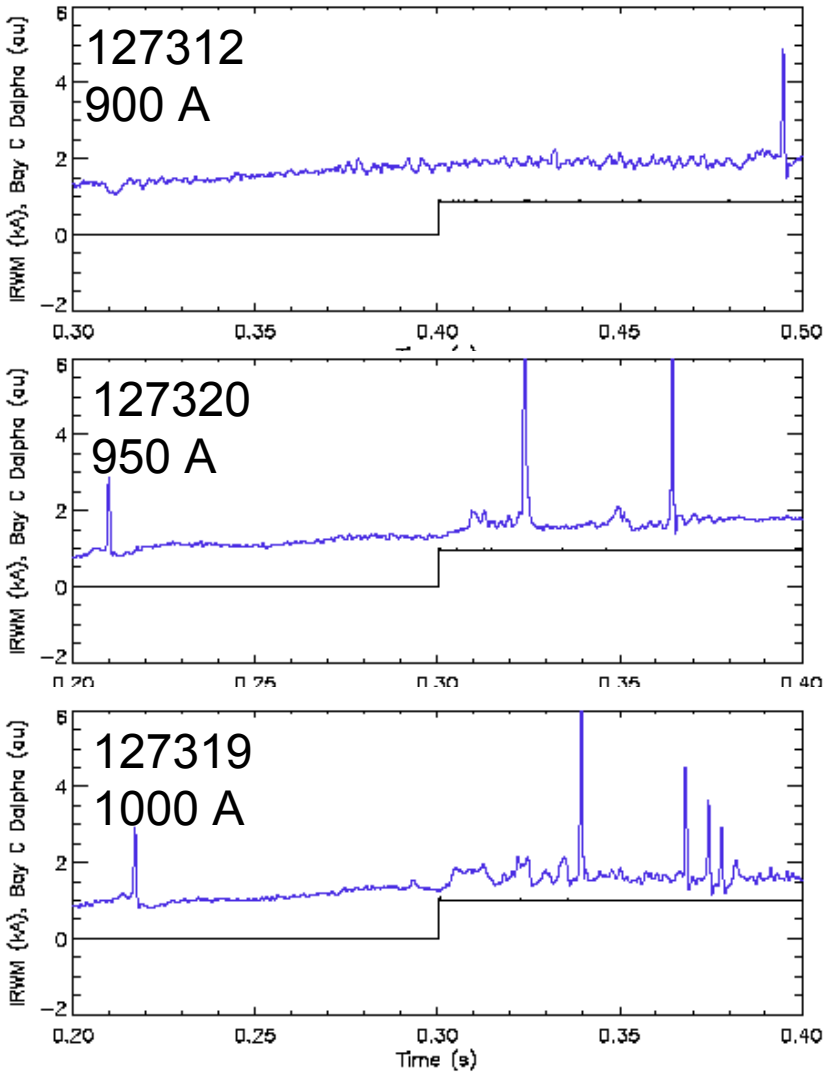
Legend: **Day allocated at Forum**

ELM Destabilization by RMP successfully triggered ELMs

- Motivation: Large ELM mitigation and/or suppression required to prevent excessive PFC damage in ITER; might be provided with Resonant Magnetic Perturbations
  - DIII-D very successful at suppressing Type I ELMs with n=3 RMP, using internal coils (2 rows)
  - Previous XP's at NSTX applied RMP with RWM/EF coils, saw ELM-triggering
- Goals of this XP
  - Determine if ELM-destabilization is really due to RMP, or if it is related to changes in recycling
  - Find threshold level (if any) of RMP for ELM-triggering
  - Collect profile data with/without RMP for P-B stability analysis
- Results: successfully explored the ELM-triggering with RMP
  - Started with ELM-free H-mode (with no RMP), ELMs started ~20-50ms after RMP application
  - Confirmed effect not due to changing wall conditions – ELM-free phase recovered when RMP is removed (no hysteresis), even within one discharge
  - Threshold current determined
  - Pedestal profile analysis underway

ELMs Destabilized by RMP in XP 809

- SPA current threshold for ELM destabilization ~950 A
- Planned analysis: correlate observed triggering with
  - Chirikov parameter (vacuum and IPEC)
    - So far, edge values > 3 for shots analyzed (>1 indicates field is stochastic)
  - Peeling-ballooning stability
    - Start with ELM-free phase
    - What path leads to stability boundary?
  - Bootstrap current calculations (XGC0)
  - Rotation, recycling, ...?



Good data obtained in XP 721 on small ELM regime between C-Mod, MAST, and NSTX

- Performed b_{ped} scan to find Type V window at lower q95
  - Looks like minimum b_{ped} of 5-6% needed in NSTX
  - Nearly identical window as last year at much higher q95 - suggests results not dependent on q95
  - More data available from XP 609 - same shape, slighly higher q95 - analysis not done yet
  - Missed fast camera data to conclusively identify small ELM windows (travel schedule conflict) -> relied on SXR, which is harder to be conclusive because of edge MHD
  - Also lost NBI src. B for 1 1/2 hrs, i.e.1/3 of run time
    - ➢ May ask for 1-2 hrs to confirm operational window with GPI
- Subject of IAEA 2008 paper with C-Mod, MAST

XP 721 confirmed in 2008 Type V ELM / no ELM β window at lower q95

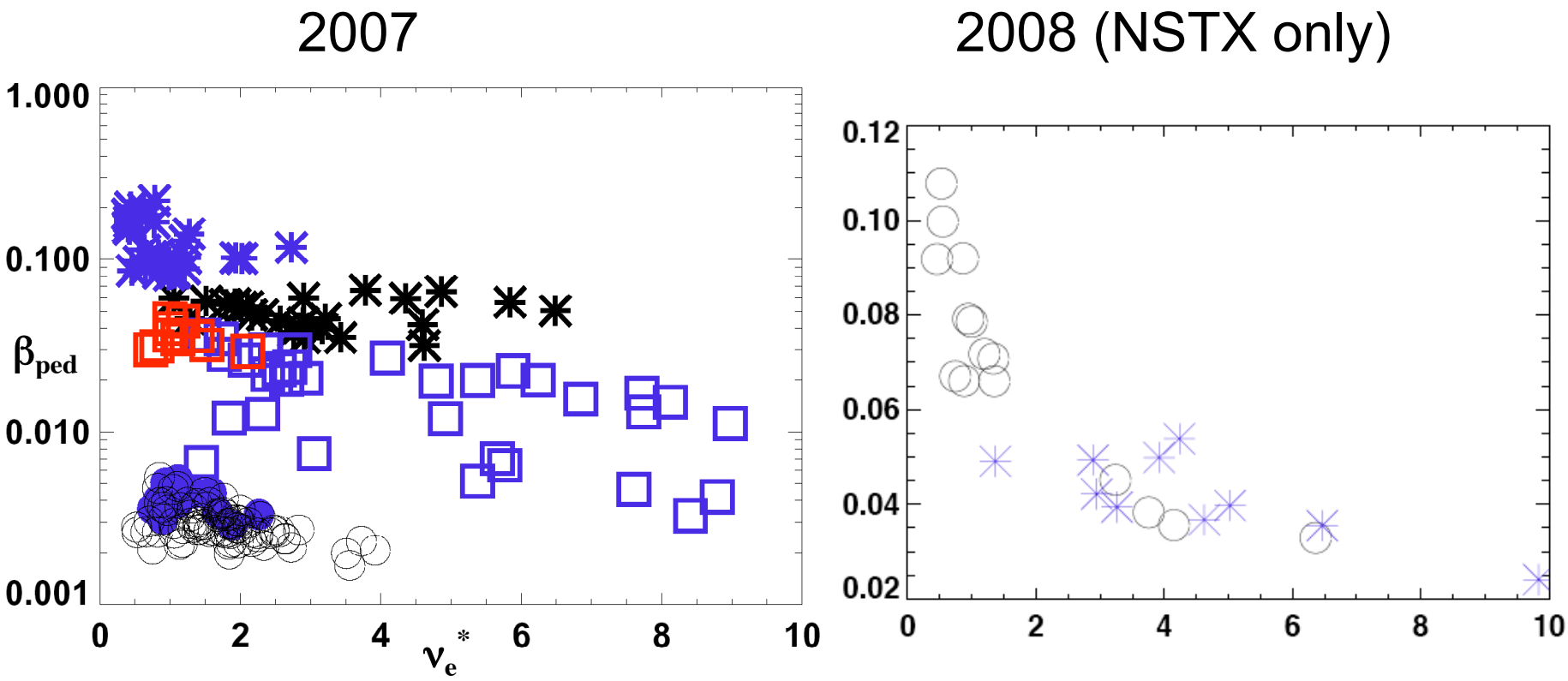


Figure 1: Small ELM edge operational space in Alcator C-Mod (circles), MAST (squares), and NSTX (stars). The color BLACK signifies no small ELMs, BLUE signifies that small ELMs were observed, and RED signifies large ELMs only, i.e. no small ELMs.

XP 609 - dependence of ELMs on *drsep* is mostly complete

- Performed d_r^{sep} scan in high $\delta \sim 0.75$
  - Several d_r^{sep} ramps and values obtained at P_{NBI} = 4, 6 MW
  - Discharges all with Type V ELMs, occasional Type I ELMs
  - Power balance data still being analyzed - some puzzles

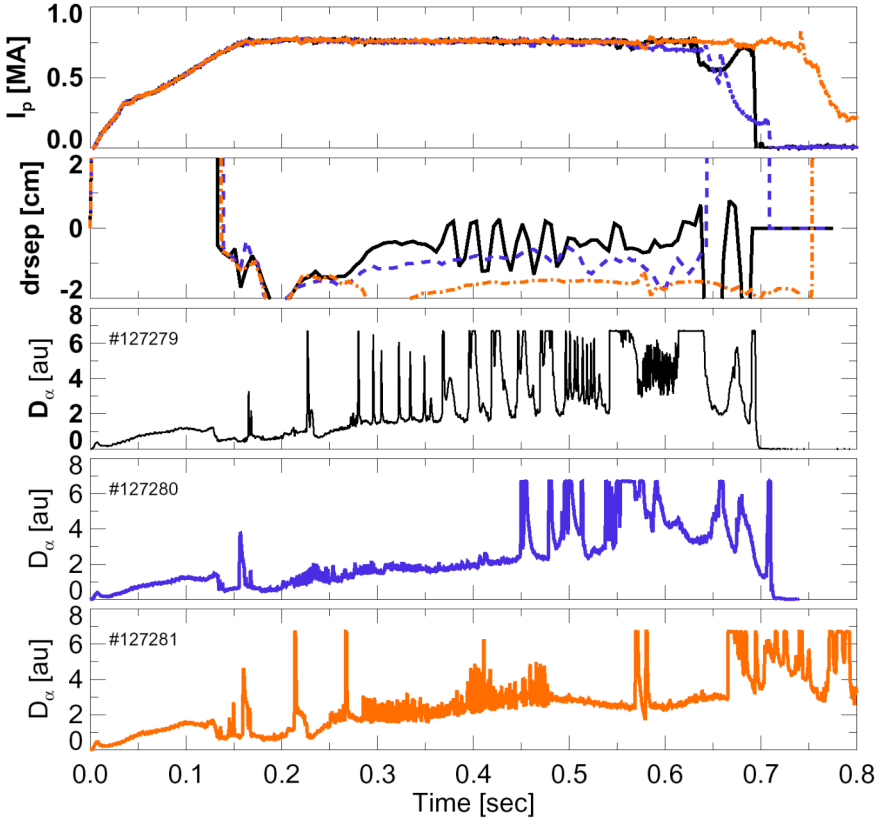
- Performed d_r^{sep} scan with low $\delta \sim 0.45$
  - Several d_r^{sep} ramps and values obtained at P_{NBI} = 6 MW
  - Type I ELMs more likely as $d_r^{sep} \sim 0$, as observed before
  - Type V ELMs more likely as d_r^{sep} made bigger
  - Power balance data still being analyzed - some puzzles

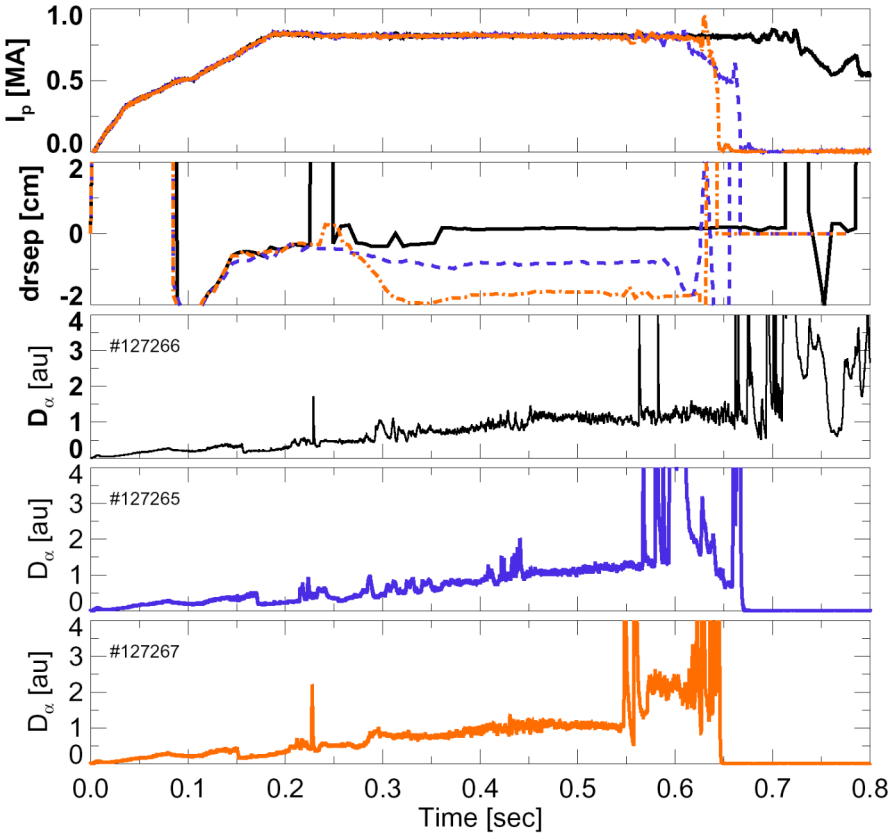
- Edge stability analysis to follow

XP 609 scanned drsep in low triangularity and high triangularity discharges

Low δ_L ~ 0.5

High δ_L ~ 0.75





Prioritized XP list - status and plans

Completed:

- ☑ **XP 721 - A. Hubbard, R. Maingi, H. Meyer** - Comparison of Small ELM Regimes in Alcator C-MOD, MAST, and NSTX (ITPA PEP-16)
- ☑ **XP 609 - H. Meyer, R. Maingi** - Dependence of ELMs and Power Balance on Magnetic Balance and Fueling (ITPA PEP-6)
- ☑ **XP 809, 818 - J. Canik, S. Sabbagh** - XPs on ELM control with RMP
- ☑ **XP 806 - S. Zweben** - Edge Electrode Biasing for SOL Control

XPs to be completed in next 2-3 weeks:

- ☐ **XP 815 - J.-W. Ahn** - SOL width characterization - **0.5 day**
- ☐ **XP 814 - V. A. Soukhanovskii** - Divertor detachment in highly-shaped plasmas - **0.5 day**
- ☐ **XP 816 - R. Maqueda** - Edge Characterization in high performance discharges - **0.5 day + 1 day**

Legend: **Day allocated at Forum**
Pending additional run time allocation

Prioritized XP list (continued)

- **XP 824 - C. Skinner** - Gas and particle balance - **0.5 day + 0.5 day**
- **R. Maingi, A. Kirk, T. Osborne** - Dependence of pedestal structure on aspect ratio (PEP 9) - **0.5 day**

To be run in Lithium Age and thereafter (April - June 2008)

- **D. K. Mansfield** - Injection of lithium powder - **0.5 day**
- **D. K. Mansfield** - Initial Use of Dual LITER for ELMs Mitigation and Evaporator Characterization - **1 day + 0.5 day**
- **R. Maqueda** - Edge turbulence and blobs - **0.5 day + 0.5 day**

- **L. F. Delgado-Aparicio** - Role of neoclassical impurity transport in the NSTX gradient region - **0.5 day**
- **K. Tritz** - Study of Type V ELMs and edge gradients - **0.5 day**

Legend: Day allocated at Forum
Pending additional run time allocation