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NSTX

Boundary Physics Research in NSTX

Rajesh Maingi (ORNL)

on behalf of the **NSTX Team**

19th Program Advisory Committee Meeting

Princeton, NJ

Feb. 21-23, 2006

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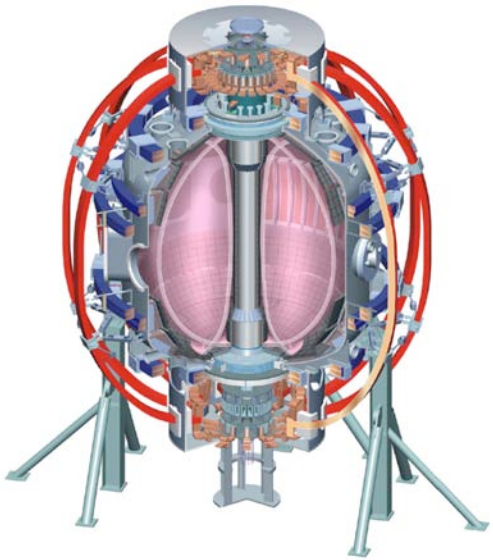

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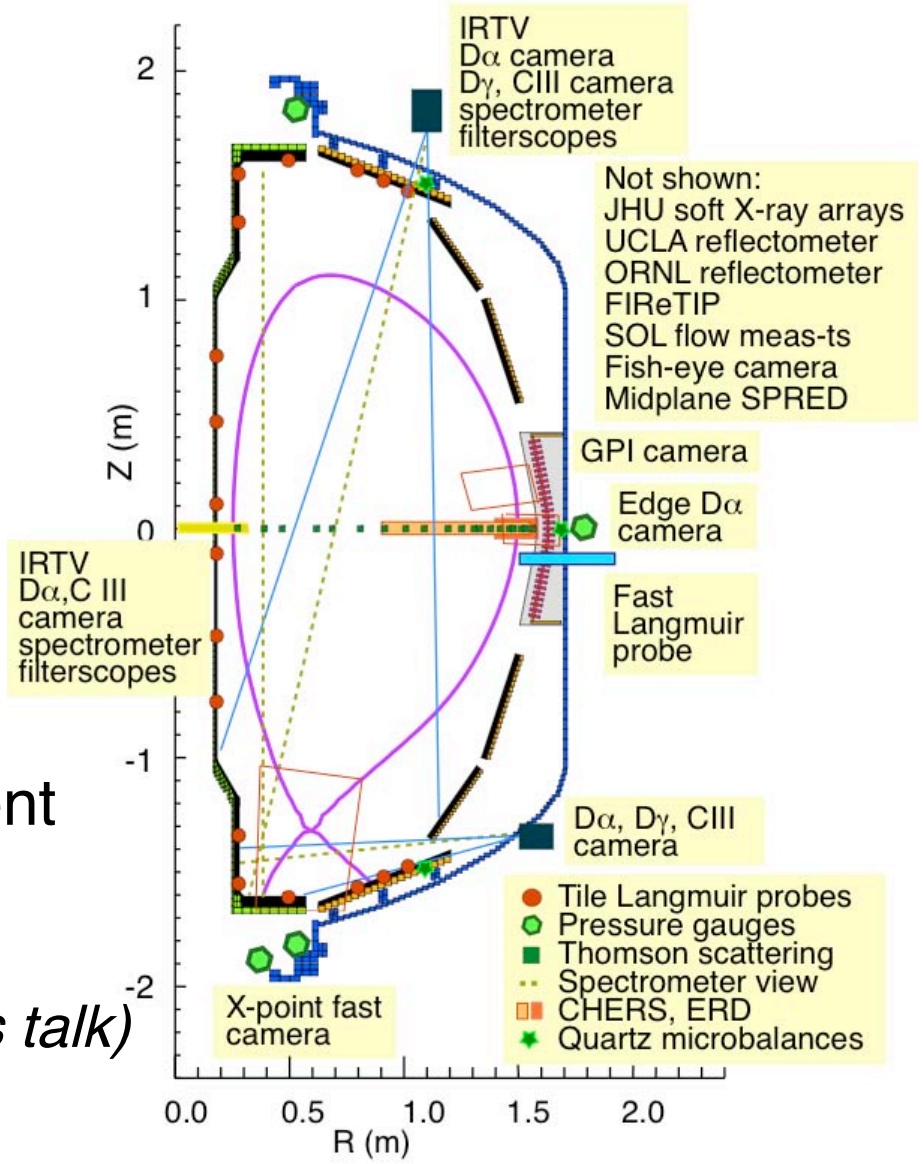
NSTX Boundary Physics Program Contributes to Burning Plasma Research and ST physics

Topics

- **L-H transition physics and power threshold studies**
- **H-mode pedestal scaling**
- **Enhanced Pedestal regime**
- Small ELM regimes
- Edge turbulence
- SOL power flow and detachment
- Material migration

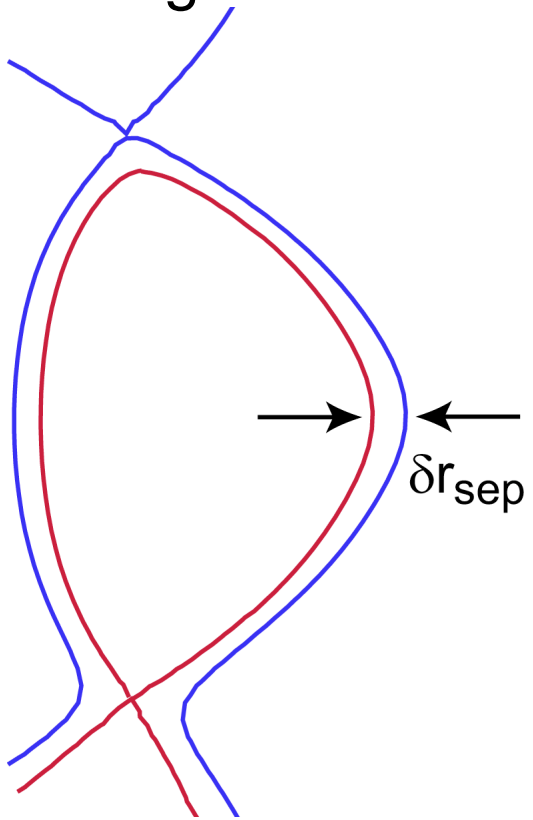
(Density control & fueling in Kugel's talk)



NSTX studying basic L-H Transition Physics

- ITER auxiliary heating power within a factor of two of predicted H-mode power threshold
  - need improved understanding and better scalings

- NSTX experiments in several areas
  - Edge correlation length changes (GPI)
    - Search for zonal flows
  - Effect of shape on P_{LH} - collaboration with MAST
  - NBI vs. RF heating: collaboration with C-Mod
  - Ohmic H-modes: access to core

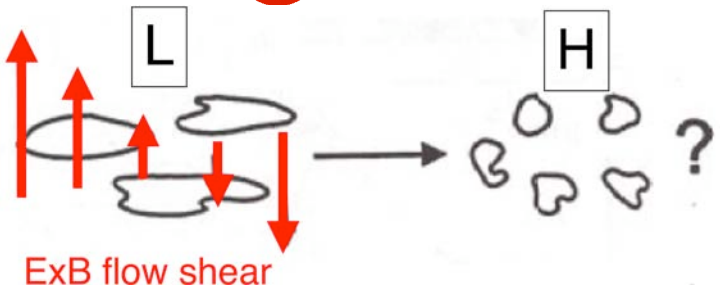


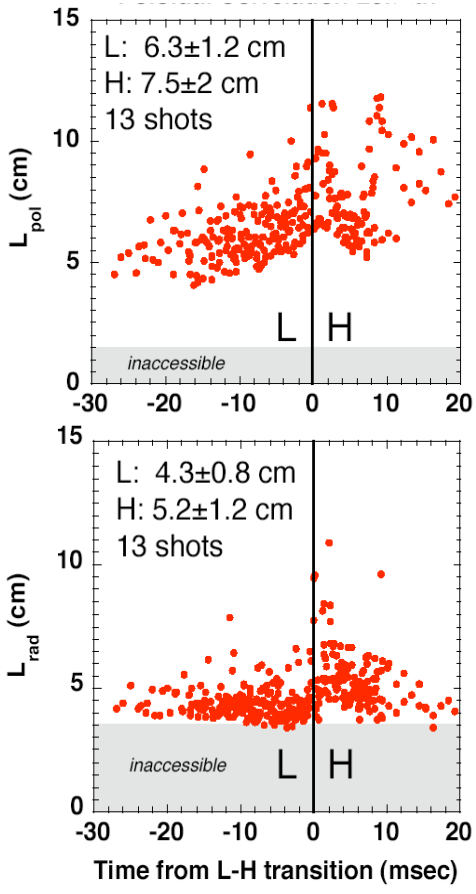
NSTX investigating leading theories for H-mode turbulence suppression

- Turbulence and recycling light reduced after L-H transition
- No substantial change in poloidal or radial correlation length
- No change in poloidal flow shear of turbulence at L-H
- Maybe change occurring radially inward of GPI signal?

Plan: 2006-7

- Where does L-H recycling signature change first? (Nova Photonics fast camera to look at many L-H transitions)
- What determines quiescent phase duration after L-H? (P_{NBI}, n_e scans)
- ITPA DSOL-15: inter-machine comparison of blob characteristics





Zweben, PoP at press 2006

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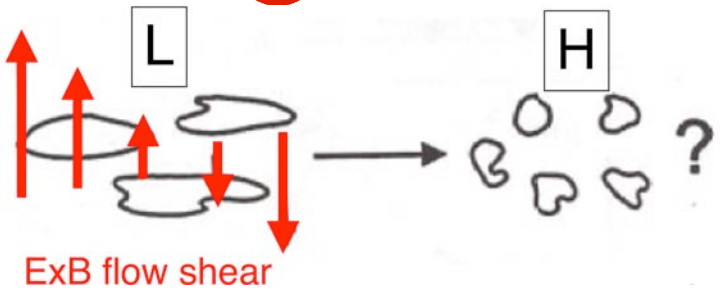

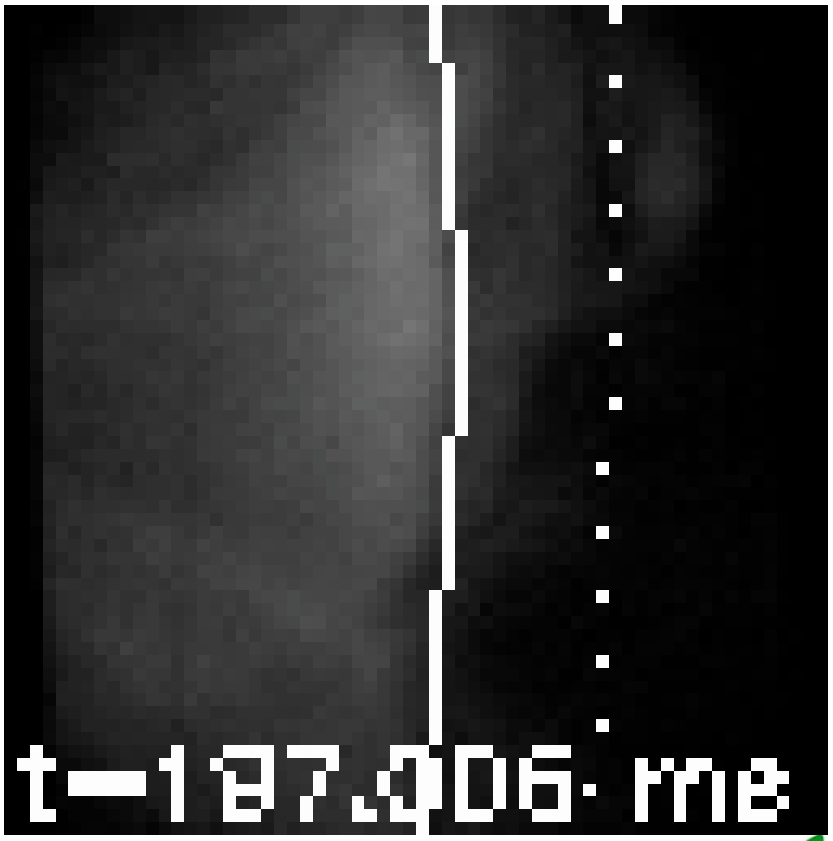

Plan: 2006-7

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- What determines quiescent phase duration after L-H? (P_{NBI}, n_e scans)
- ITPA DSOL-15: inter-machine comparison of blob characteristics

Zweben, PoP at press 2006

NSTX investigating shape and heating method dependence of power threshold

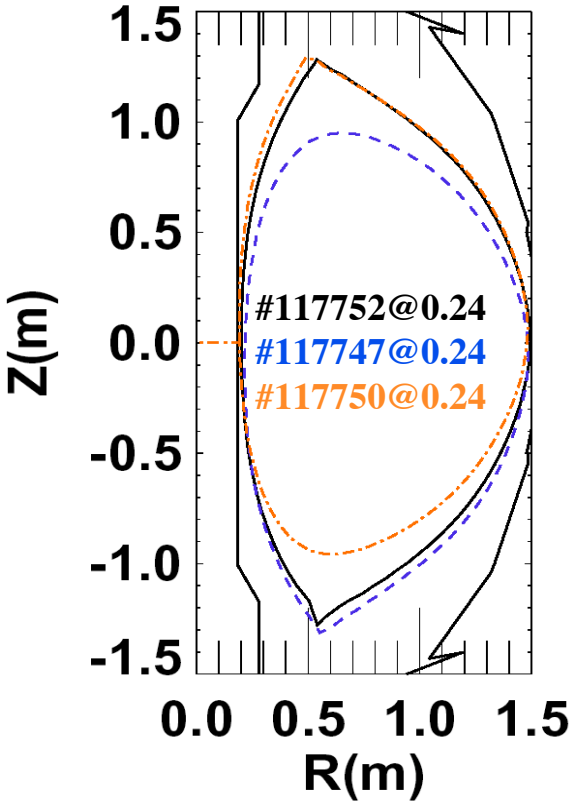
- Motivation: will ITER operation with a second nearby separatrix reduce power threshold?

NSTX 2005 results (MAST, C-Mod collaboration)

- P_{LH} lowest in balanced DN with $\delta r_{sep} \sim 0$ w/NBI heating or RF heating
- P_{LH} ~2x (~4x) higher in LSN (USN) w/NBI
- P_{LH} comparable for NBI and RF in DN

Plan: 2006

- Analyze edge gradients, flows, E_r, turbulence and correlation lengths before/after L-H
- Use RF and NBI comparison to assess importance of SOL flows in L-H physics
- Continue development of 2-D flow field measurement



Biewer, Maingi, Meyer EPS 2006

NSTX, MAST and DIII-D assessing dependence of H-mode pedestal on aspect ratio

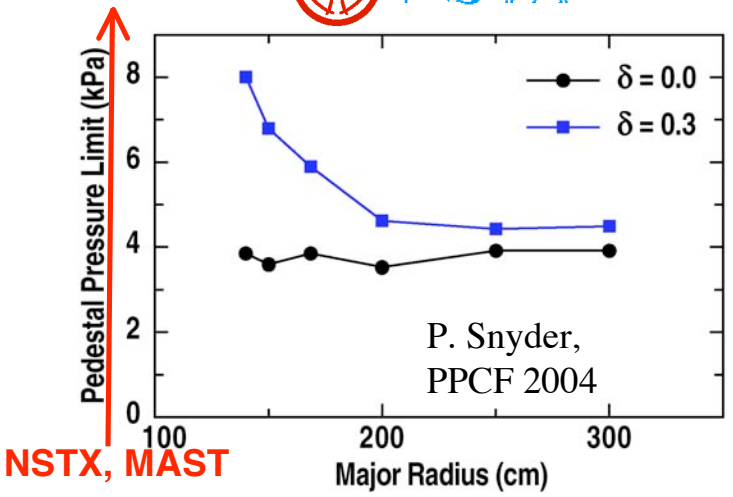
- Pedestal height can be estimated if maximum P', width known
- Calculations show p' depends on R/a
- Previous DIII-D and JT-60U study (Hatae) suggested $T_{e,wid} \sim (a/R)^{0.6}$

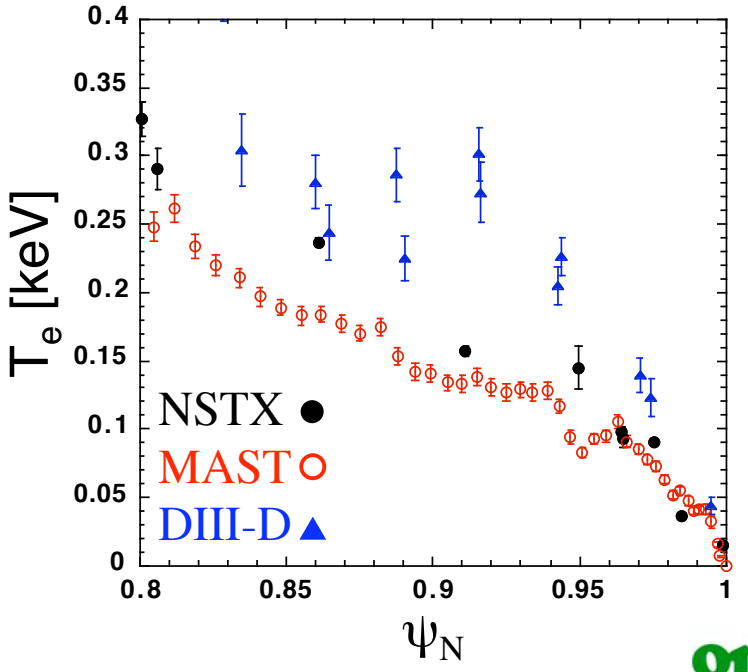
Results

- Common shape with $\nu^*_{ped} \sim 1$ and $\rho^* \sim .01$ achieved
- p' being assessed; $T_{e,wid}$ smaller in NSTX, MAST than DIII-D

Plan: 2006

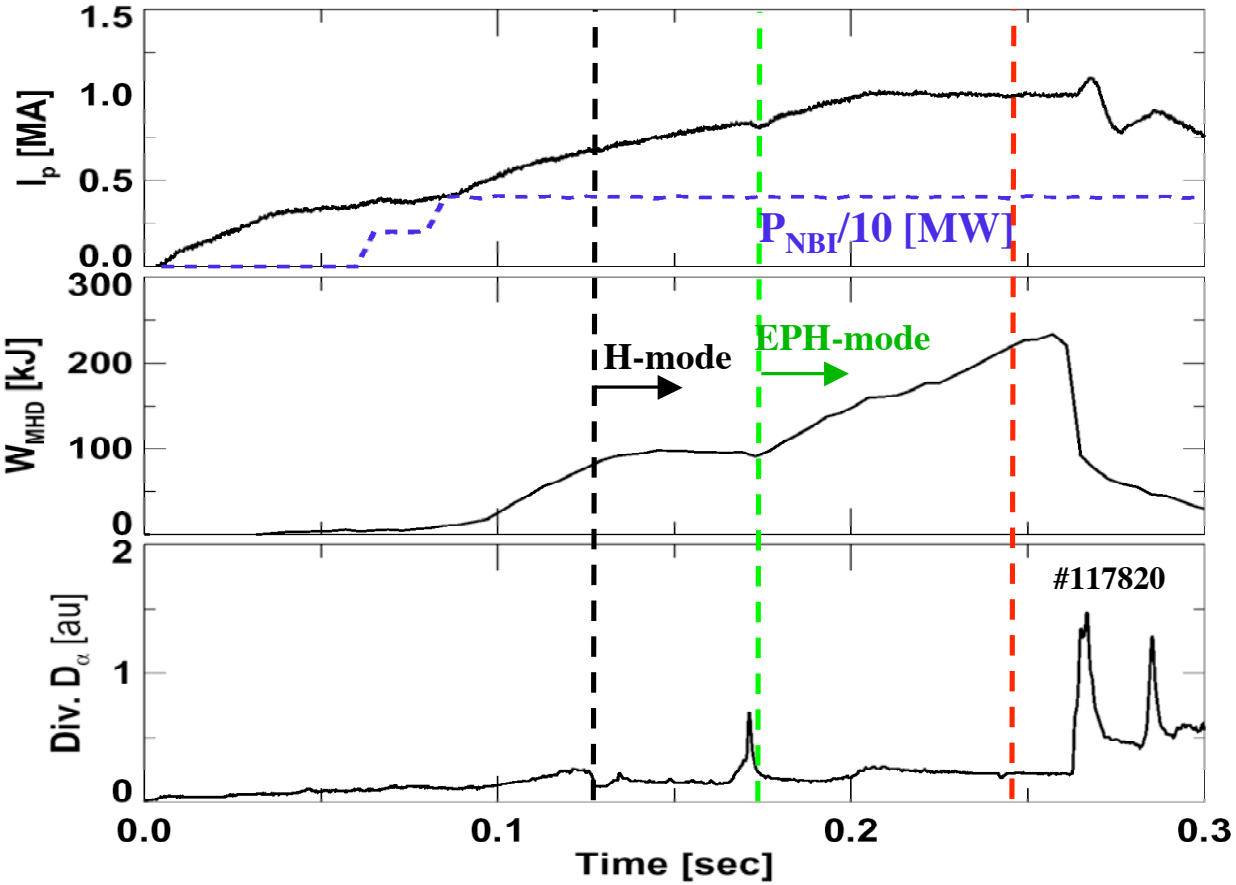
- Finish pedestal analysis and start edge stability analysis with new edge MSE chan.
- Improve shape match and obtain data at lower ν^*_{ped} - enabled by lithium
- ITPA PEP-9: Dependence of pedestal structure on aspect ratio

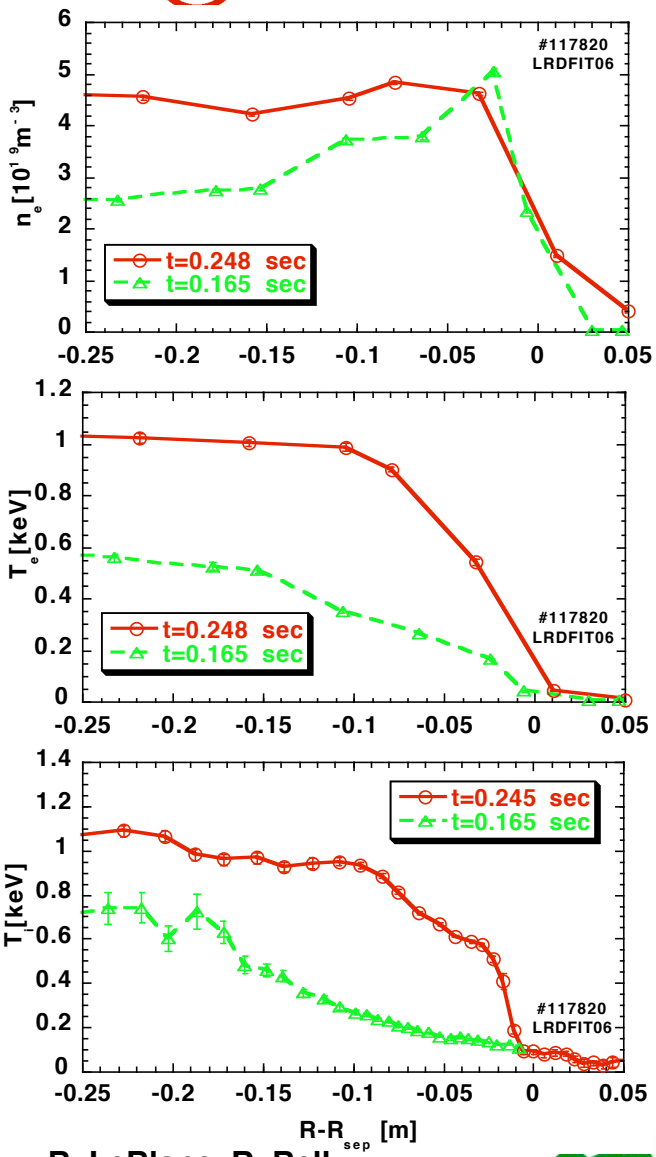




Maingi, IAEA 2006

Transition to an Enhanced Pedestal H-mode enables pedestal $\nu^*_e \sim 0.1$ in NSTX





- Pedestal $\nu^*_e \sim 0.5$-1 in normal H-mode
- Hypothesize that current hole during these discharges restricts $\beta_N \leq 4.5$

Maingi, PRL 2006 to be submitted

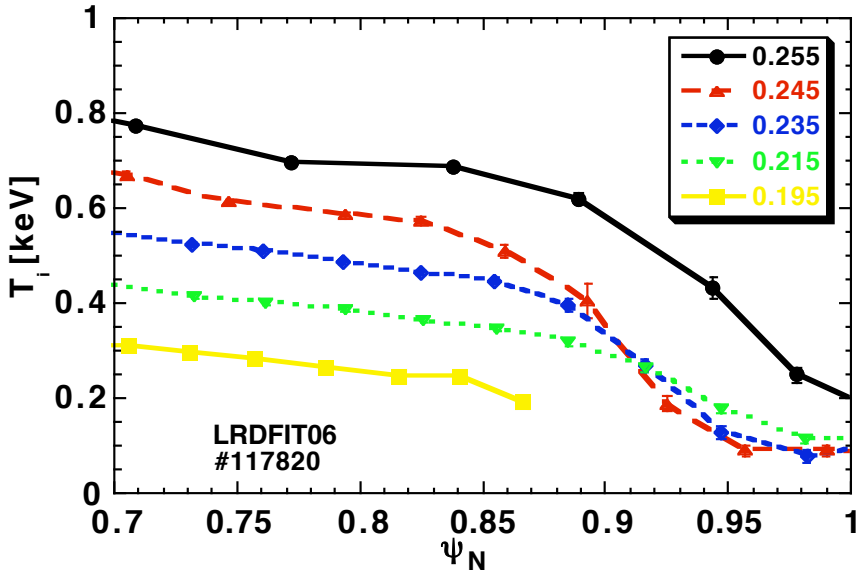
B. LeBlanc, R. Bell

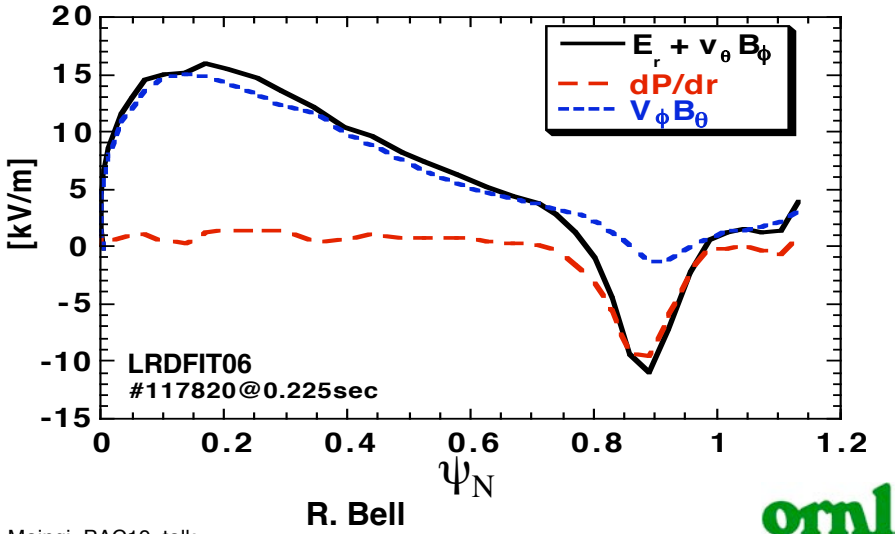
Enhanced Pedestal H-mode is a step toward FY08 milestone: edge and divertor studies at low ν^*

- Previous $T_{ped} < 250$ eV in NSTX (and MAST), as predicted by some theories (e.g. Guzdar PoP 2005) which project little/no access to high T_{ped} in STs

Plan: 2006-7

- More EP H-modes needed
- Lengthen duration by tailoring of the heating and fueling profiles to avoid premature stability limit
- Trigger mechanism not yet understood: vary magnetic balance during ramp-up to affect edge stability
- Use in concert with lithium to reduce ν^* further





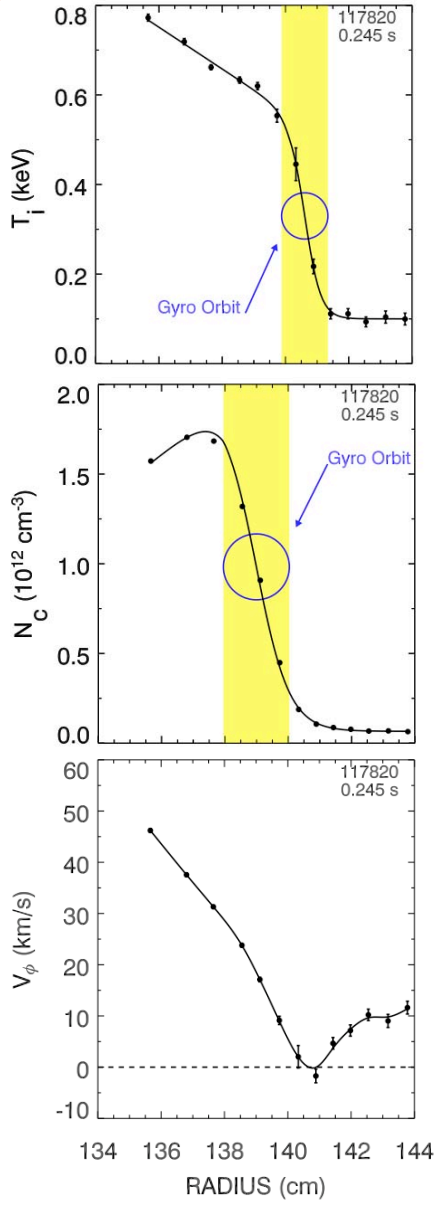
R. Bell

Enhanced Pedestal H-mode is a fundamental transport testbed

- Edge scale lengths for both T_i and n_C approach the gyro-diameter during EP H-mode
- Ion gyroradius $\rho_i \sim 0.7$ cm relative to |B|, owing to combination of local $T_i \sim 350$ eV and and |B| ~ 0.35 T at outer midplane
- Ion poloidal gyroradius $\rho_i \sim 1.4$ cm
- Banana width as minimum step size ~ 1-2 poloidal gyro-diameters
- Cannot be studied except in a low field machine with reasonably high T_i and excellent measurement capability

Plan: 2006-7

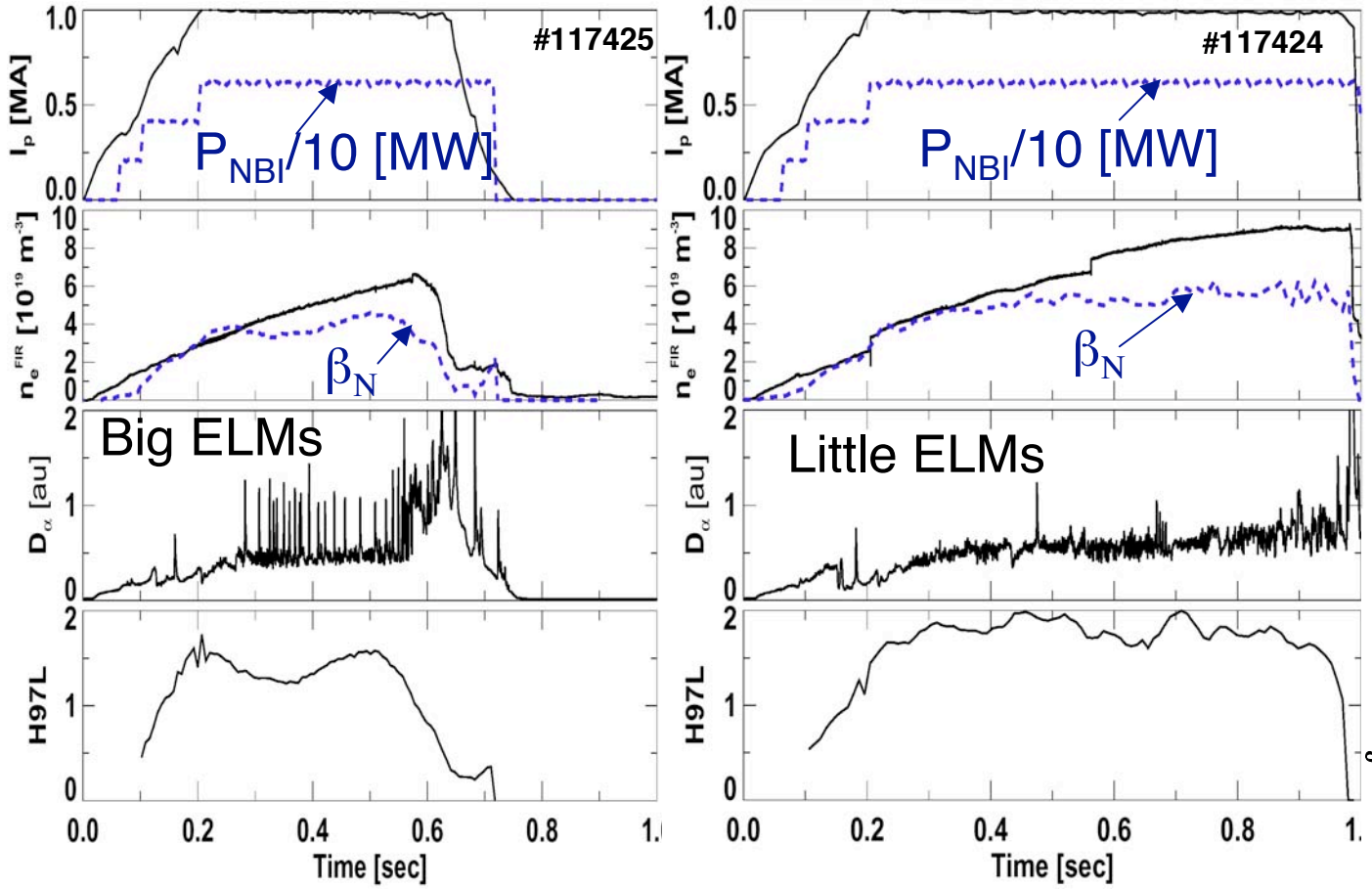
- Near term estimate of orbit squeezing effects
- Poloidal rotation will complete E_r measurement



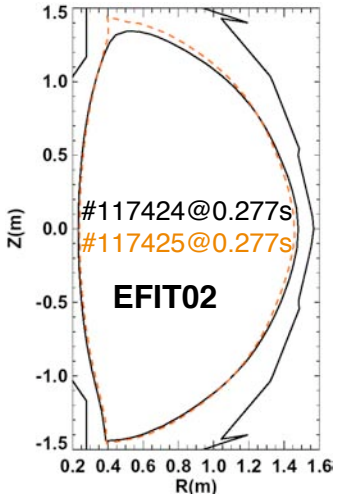
Outline

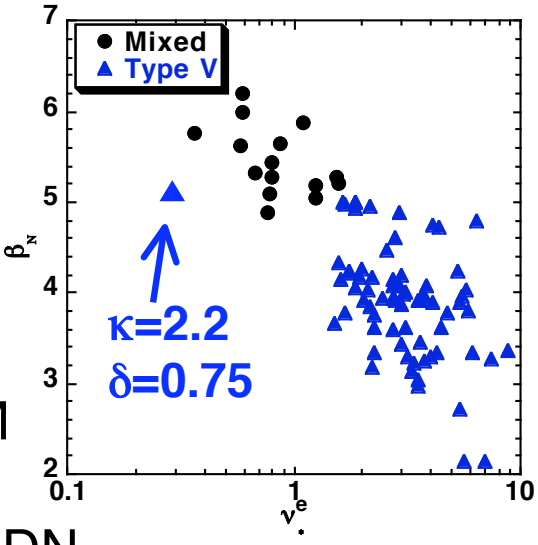
- H-mode power threshold
- H-mode pedestal scaling
- Enhanced Pedestal regime
- **Small ELM regimes**
- **Edge turbulence**
- SOL power flow and detachment
- Material migration

NSTX investigating sensitivity of ELM size to changes in the magnetic balance



δ_r^{sep} ~ 0.5cm difference



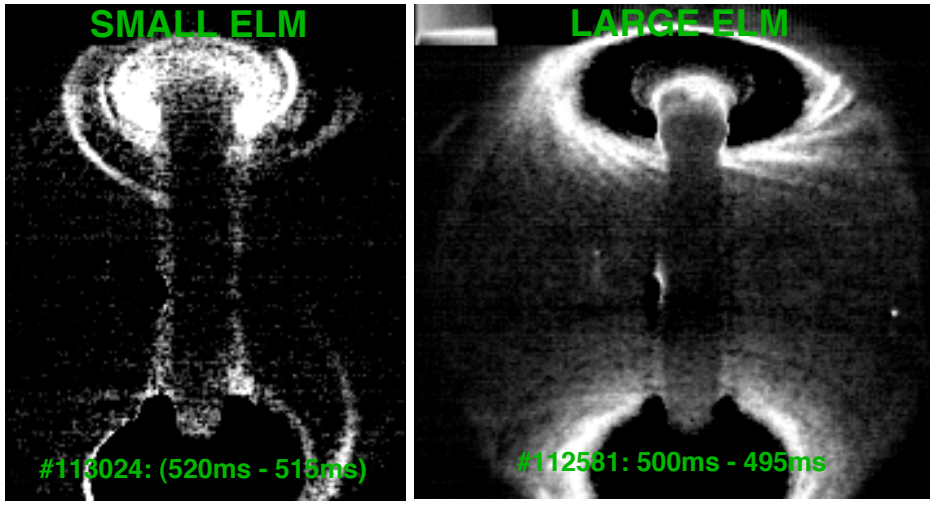


- FY 2006-7: perform detailed δ_r^{sep} scan to identify ELM boundary and help assess ITER's low δ_r^{sep} scenario
- ITPA PEP-6: Pedestal Structure and ELM stability in DN

Gates PoP 2006 at press, Maingi APS 2005

NSTX studying basic ELM stability physics through structure differences between small and large ELMs

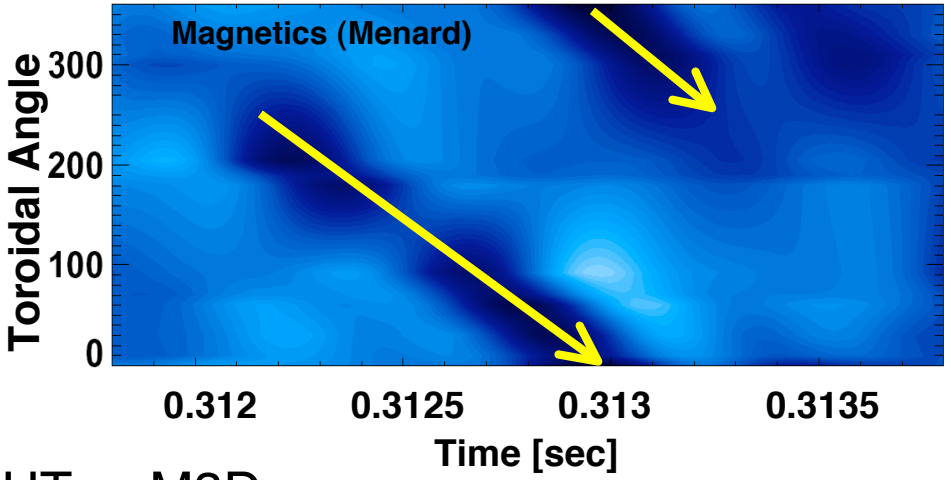
- Small ELMs are low-n, large ELMs are higher-n
- Small ELM can last up to 1 msec
- Low-n filaments appear during non-linear evolution via coalescing of high-n modes (Snyder PoP 2005)
- Non-linear phase from Cowley $\sim (\tau_a^2 \tau_E)^{1/3} \sim 100$ μsec!?
- Small ELMs must be in linear phase - low-n yet small amplitude theoretically inconsistent?



Bush (ORNL)

Plan: 2006-7

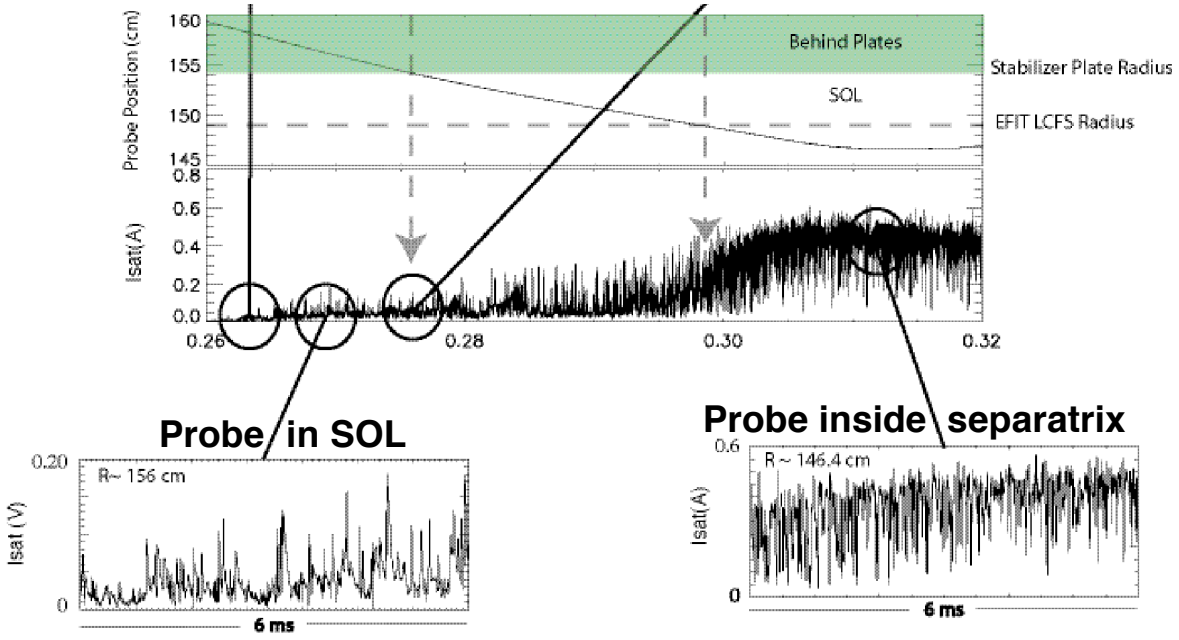
- ITPA PEP-16: small ELM regimes in NSTX, C-Mod, and MAST
- Document small ELM structure with all diagnostics simultaneously (new fast IR camera in FY 07)
- ITPA PEP-10: radial depth of ELMs
- Simulate with DCON, ELITE and BOUT or M3D



Maingi, APS 2005

Edge turbulence studies focus on dependence of turbulence on confinement mode, shape and ν^*

- Many diagnostics for edge turbulence studies: GPI, reciprocating probe, correlation reflectometer, FIReTIP
- Probe shows I_{sat} peaks in SOL and holes after crossing separatrix - resistive interchange?



Plan: 2006-7

- Perform controlled density (ν^*) scan with lithium and obtain data with all turbulence diagnostics
- Examine changes in turbulence as density limit is approached
- Complete dataset of L and H-mode comparisons with fast probe and other diagnostics
- Assess onset of electromagnetic turbulence as edge beta increased

Outline

- H-mode power threshold
- H-mode pedestal scaling
- Enhanced Pedestal regime
- Small ELM regimes
- Edge turbulence
- **SOL power flow and detachment**
- **Material migration**

Edge and SOL heat transport research relevant for ITER and long pulse ST development

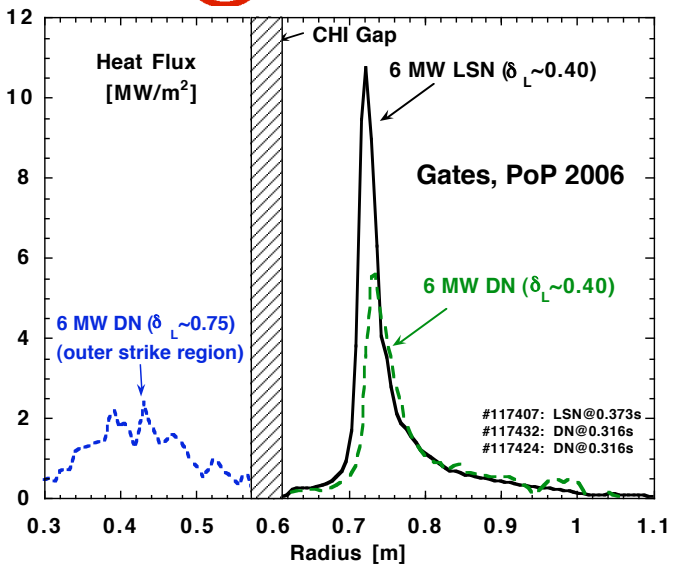
- High peak heat flux can occur in STs
  - high P/R, due to small R
  - short $L_{||}$ from outer midplane to target
  - low poloidal flux expansion in low triangularity shapes

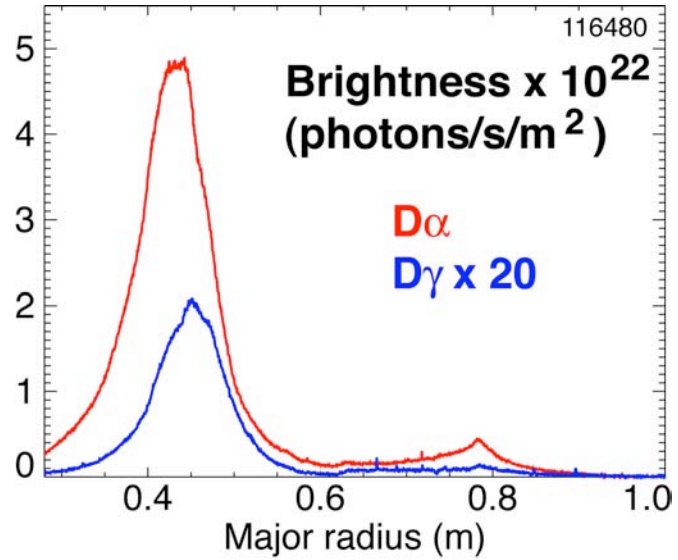
NSTX result: q_{peak} up to ~ 10 MW/m^2

- Outer divertor in conduction-limited, high recycling heat transport regime
- Inner divertor usually detached

Plan: 2006-7

- Controlled density (ν^*) scan with lithium to assess when outer divertor enters sheath-limited regime and inner divertor reattaches
- Evaluate impact of transient events on divertor with new fast IR camera

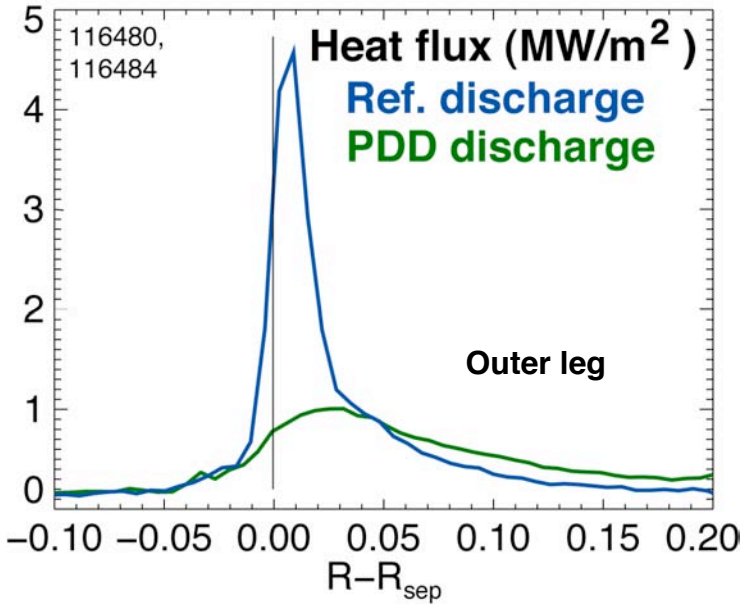




Soukhanovskii, LLNL APS 2005

Detachment onset and compatibility with high performance important for next step STs and CTF

- Detachment routine on inner leg in NSTX
- Partially detached divertor (PDD) observed only with private flux region gas puffing in outer leg of NSTX
  - Outer leg heat flux profile peak shifts several cm radially away from strike point and value decreases
  - Spectroscopic signs of recombination
  - First high-power ST with PDD



Plan: 2006-7

- Document outer divertor baseline and PDD discharges
- Lengthen detachment duration with improved gas injectors
- Develop detachment scenarios for high performance plasmas (higher input power, more highly shaped plasmas)
- Compare onset with detachment models used for higher R/a tokamaks
- Evaluate detachment by impurity injection
- Evaluate impact of ELMs on divertor detachment with new fast IR camera

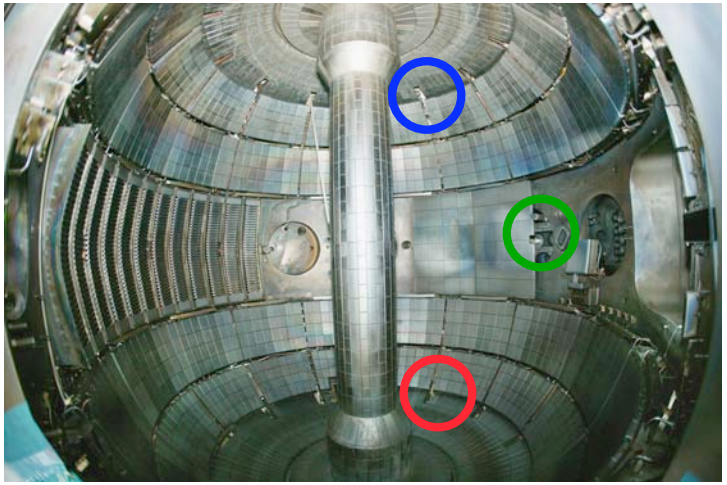
Soukhanovskii, LLNL APS 2005

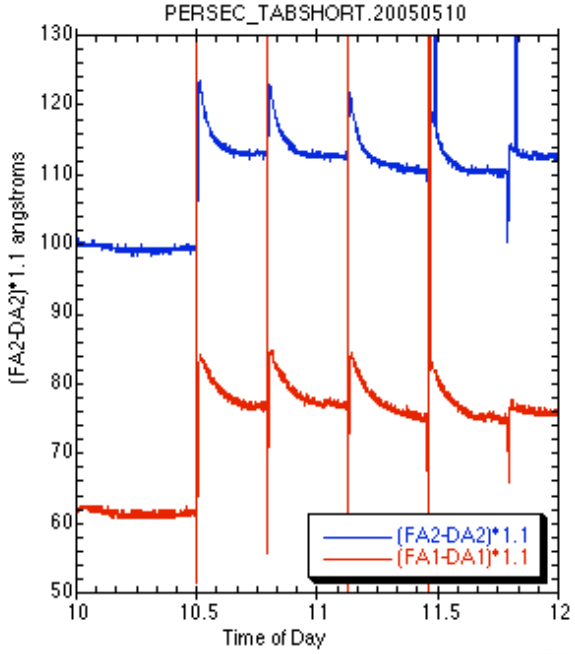
Material migration studies relevant to PFC integrity and tritium retention in ITER

- Three quartz micro-balances (QMB) installed in NSTX (circles) - measure film thickness
- Biggest effect: first discharge of day shows substantial net deposition (10-15 Å), and last discharge shows net erosion (5-10 Å)
- *If QMBs representative of vessel interior* then equivalent thickness of fuel D used is ~1Å during each discharge over entire vessel SA
  - Large-scale mass migration

Plan: 2006-7

- Determine if deposition (erosion) on first (last) discharge related to HeGDC
- Measure dependence of erosion on input energy and pulse length
- ITPA DSOL-18: material migration study with ASDEX-Upgrade and JET
- Dust measurements with *in situ* detector





Skinner, APS 2005

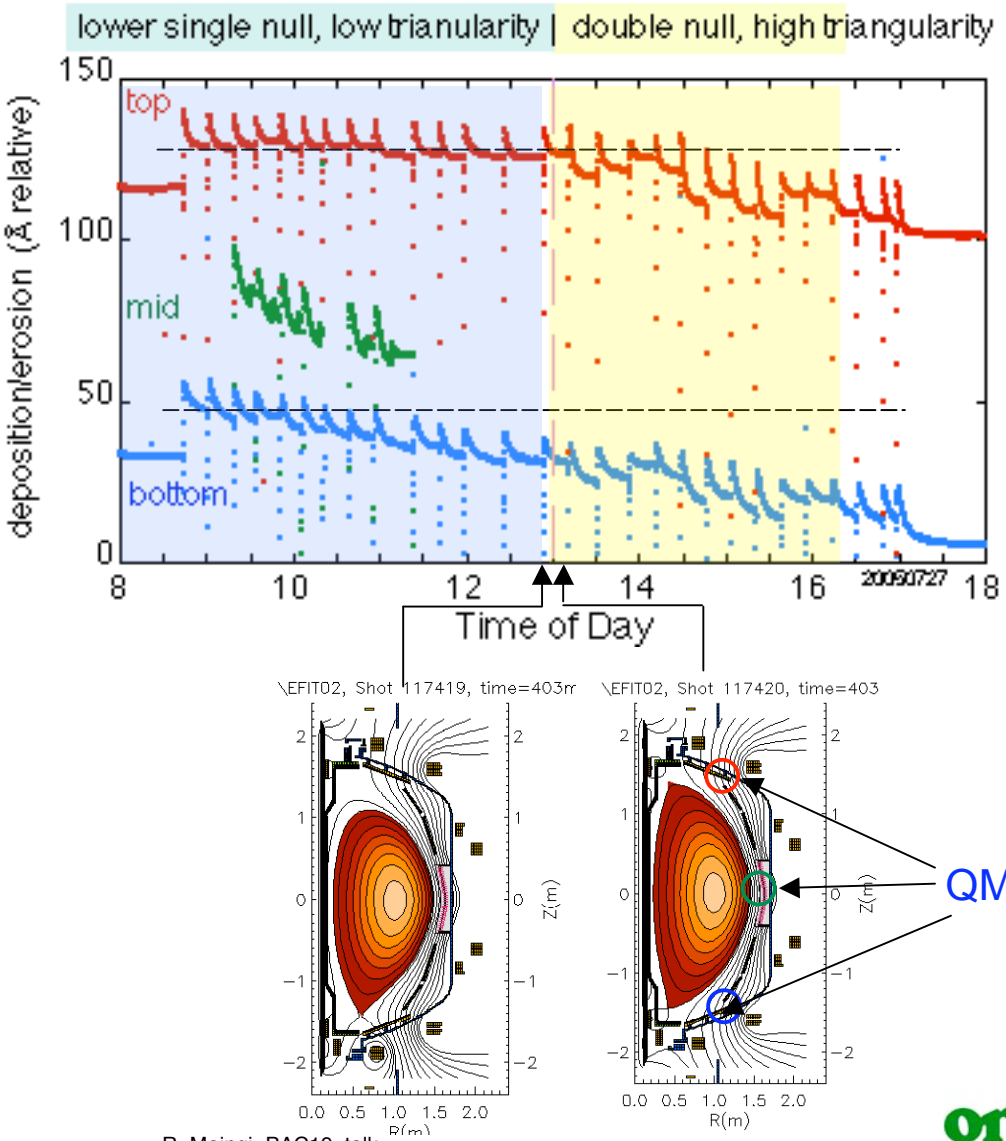
NSTX determining shape dependence of erosion and deposition

- In low triangularity LSN shape, QMB shows ~ constant erosion rate in lower divertor and no thickness changes in upper divertor
- In high triangularity DN shape, both upper and lower divertor show erosion at the same rate as the LSN!
- Which is important: δ, number of divertors, or δ_r^{sep}?

Plan: 2006-07

- Measure changes in erosion with detailed δ_r^{sep} scan

Shot times marked by transient.



Skinner, APS 2005

R. Maingi, PAC19 talk

NSTX Boundary Physics Plan in FY 2006 addresses 2006 milestone and ITPA commitments

- Recycling control and long pulse development with lithium - 3 days
- Dependence of pedestal on aspect ratio - 1 day
- Small ELM regime comparison - 1 day
  - Small ELM consistent dataset - piggyback
  - ELM radial depth - piggyback
- Controlled density scan in L and H-mode, including density limit turbulence study and dependence of material migration on pulse length and HeGDC - 1 day
- Divertor heat load mitigation and detachment and high performance compatibility - 1 day
- Supersonic gas jet fueling - 1/2 day

Boundary physics experiments to be considered for FY 2006 after milestones and ITPA

- Edge turbulence and transport
- Type I ELM heat pulse propagation
- ELM suppression studies with resonant magnetic perturbation
- Heat flux mitigation with impurities
- Controlled δ_r^{sep} scan for ELMs and material migration

Many important experiments will be deferred to 2007-8 due to run time constraints in 2006

- Diagnostic optimized plasmas for edge radial transport and turbulence modeling
- SOL flows
- Edge biasing for density control in H-modes
- Dedicated dust studies
- Electromagnetic turbulence at high edge β
- Effect of transients on SOL heat flow and detachment (new IR camera in 2007)
- Enhanced Pedestal H-mode extension and assessment (poloidal CHERs in 2008)
- Heat flux mitigation at low collsionality (2008 milestone)