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Boundary Physics Research on NSTX: Progress and Plans

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on behalf of the NSTX Research Team

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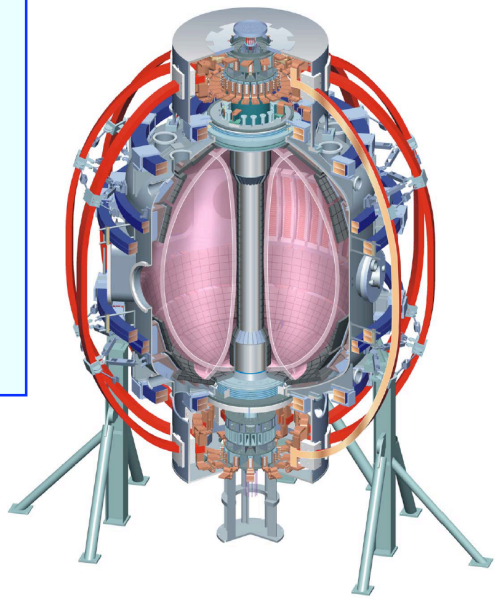
NSTX PAC-21 Meeting
18 January 2007
Princeton Plasma Physics Laboratory
Princeton, NJ



Boundary Physics Research on NSTX: Talk Outline

- General program description
- Diagnostic and facility upgrades
- Progress and Plans for FY07 - FY09 in Sub-Topical areas
- Experimental Research Plan for FY07 campaign

Experimental program is guided by Milestones, ITPA, Joint Proposals, ST development path needs

- **NSTX Edge Physics Milestones:**
  - **FY08** Study variation and control of heat flux in SOL
  - **FY09** (incremental) Characterize performance of a liquid lithium divertor

- **ITPA participation**
  - **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
  - **DSOL-15** Inter-machine comparison of blob characteristics
  - **DSOL-17** Cross-machine comparison of pulse-by-pulse deposition
  - **DSOL-19** Impurity generation mechanism and transport during ELMs (considering)
  - **DIAG-2** First Mirror Qualification (considering)

- **ST-CTF development path needs**

Components of NSTX Boundary Physics program

- Effect of lithium coatings on recycling, density control and confinement
- Fueling studies
- Divertor heat flux scaling and control
- Edge transport and turbulence
- ELM studies
- Pedestal structure and stability studies
- Dust and deposition studies
- MARFE studies

New FY07 capabilities and diagnostic upgrades will enable progress in many Edge Physics areas

- **Facility upgrades**
  - Lithium deposition tools
  - Improved vacuum bake-out
  - Supersonic Gas Injection-Upgrade
  - Edge biasing electrode
  - Hypervelocity dust injector

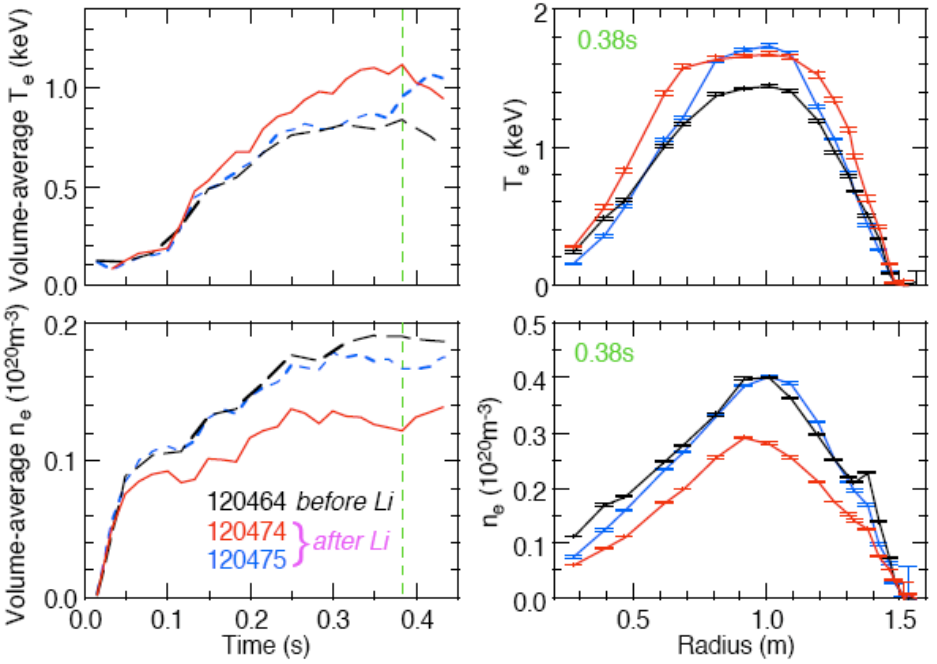
- **Diagnostic upgrades**
  - FIReTIP (2 new channels)
  - SWIFT SOL flow diagnostic
  - Deposition quartz microbalance
  - Dust detector
  - New divertor 1D and 2D cameras (for lower and upper divertor)
  - Midplane edge D_β camera
  - New p-CHERS system
  - Fast reciprocating Mach probe

Investigate lithium coating effects on particle control and plasma performance in a divertor configuration

- **FY09 Incremental Milestone: Characterize performance of a liquid lithium divertor**
- **Endorsed by PAC-19 as high priority work**

Results

- **2005**: recycling and density reduction demonstrated in LSN L-mode plasmas with Li pellet injection
- **2006**: Performed 12 Lithium Evaporation Cycles
  - short-term reduction in n_e 5-25 %, higher central T_e, T_i, global τ_E improved by 10 – 20 %
  - long-term, persistent reduction in oxygen emission (several days)
  - Li coating behavior: Passivation by residual H_2O, CO_2; intercalation of Li into graphite; Evidence for migration of lithium away from divertor strike points



M. Bell, H. W. Kugel APS 2006; R. Majeski, H. W. Kugel IAEA 2006

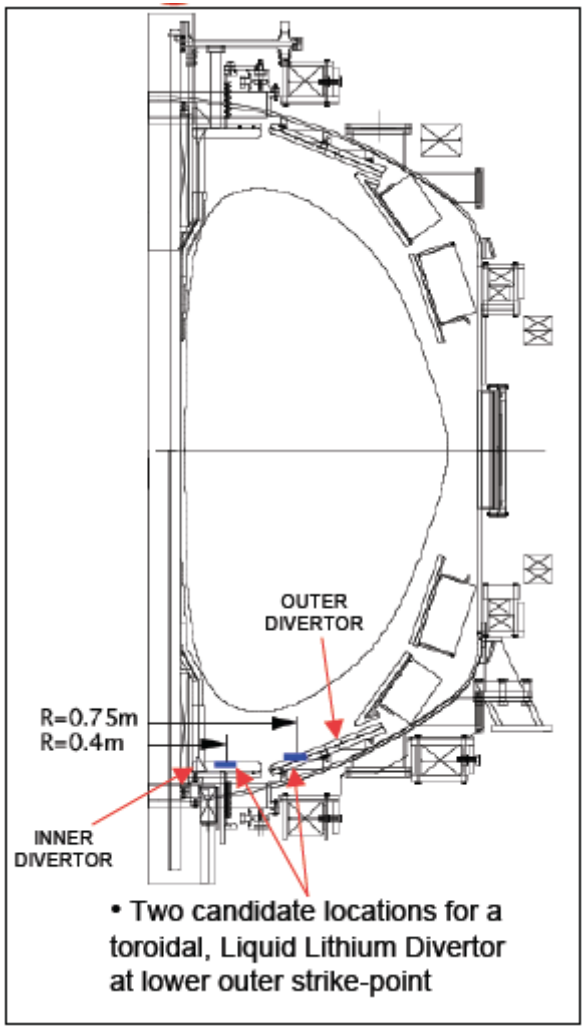
FY07 lithium experiments: improve Li deposition techniques, improve understanding of Li effects

Plan for FY 2007

- Li deposition experiments:
  - Improve LITER (higher temperature, re-aim, larger barrel)
  - Inject Li powder using LPI
  - Extend Li pellet injection to H-mode plasmas
- Develop specifications for proposed liquid lithium divertor module

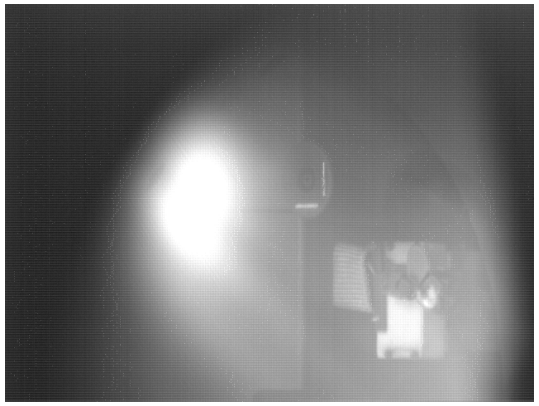
Plans for FY 2008-2009

- Plan for FY08 is TBD based on FY06-FY07 results
- Hardware options being discussed: DIMES-like lithium probe, two divertor LITER-type probes, lithium dust injection system
- Upgrade diagnostics for lithium environment
- Lithium divertor module in FY09 (pending funding review)



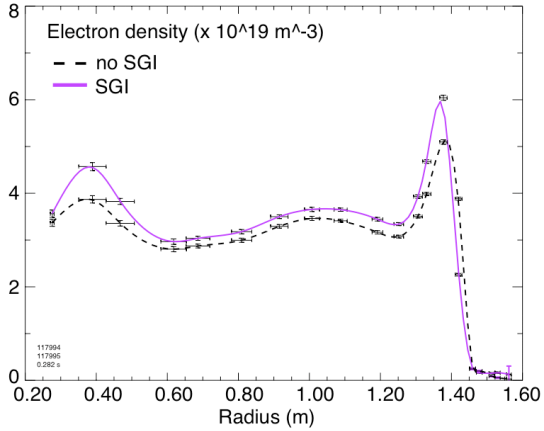
Advanced fueling tools to support density control program

- **Presently using conventional and supersonic gas injection for fueling**
- **Additional options: cryogenic pellet and compact toroid injectors**



2005-2006 Supersonic gas jet fueling results

- Mach number $M = 4$ (measured), $v_{flow} = 2400$ m/s, $v_{therm} \sim 1100$ m/s
- Measured fueling efficiency 0.1 - 0.4
- Reliable H-mode access and low H-mode power threshold, different ELM character



Plan for FY 2007

- Upgrade for higher pressure and independent gas system
- Fully integrate in long-pulse H-mode scenarios

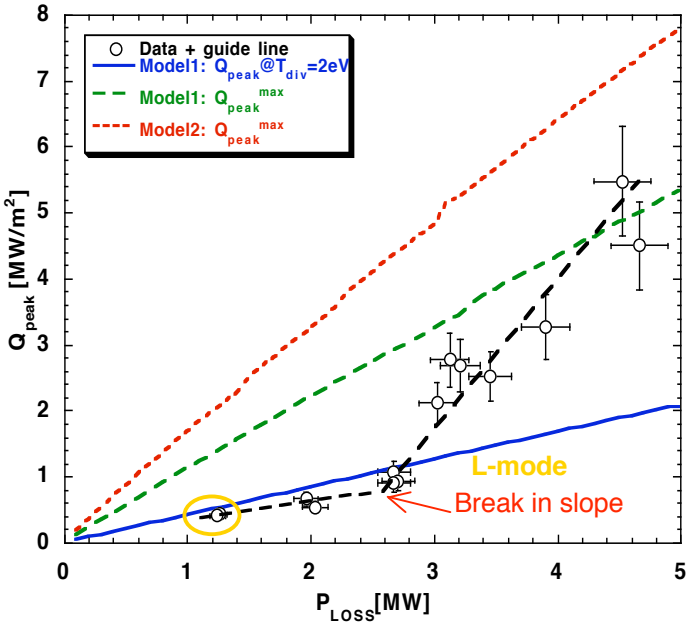
Soukhanovskii EPS 2006, APS 2006

SOL heat flux control is a high priority task for NSTX and ST-CTF

- **Compact divertor in ST - critical to understand and control SOL profiles and divertor heat flux**
- **FY08 Milestone: Study variation and control of heat flux in SOL**
- **Could contribute to ITPA database**

2005-2006 results

- Obtained L-mode T_e and n_e midpl. SOL profiles
- Obtained H-mode peak heat flux scaling and λ_q scaling with input power and plasma current
- Present NSTX scaling shows higher λ_q scaling than tokamak scalings (Kallenbach J. Nuc. Mater. 337-339, 381, 2005: $\lambda_{Te} = 3.1\text{x}10^{-3} R_0$, $\lambda_q = 2/7\ \lambda_{Te}$)



Plan for FY 2007 - 2008

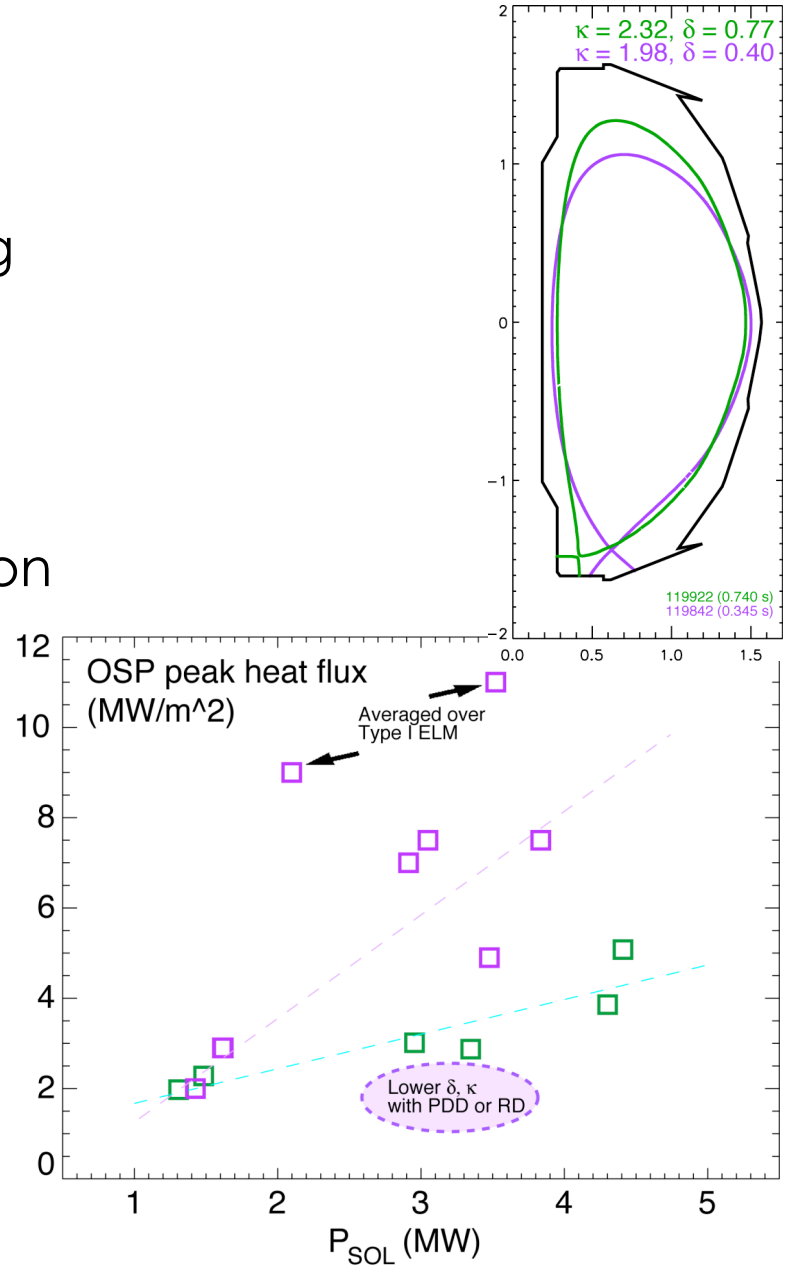
- FY 2007 high priority: Dedicated SOL width scaling experiment
- FY 2007 - 2008 - SOL width control with biasing electrodes (in collaboration with LLNL theory group)

J. Boedo IAEA 2006, Maingi PSI 2006

Divertor steady-state heat flux reduced by 2-5 using radiative divertor or poloidal flux expansion

2005-2006 Results

- OSP peak heat flux reduced (x 2-5) using high recycling radiative divertor and partially detached divertor regimes
- Significant (x 2-3) reduction in peak divertor heat flux using high flux expansion geometry



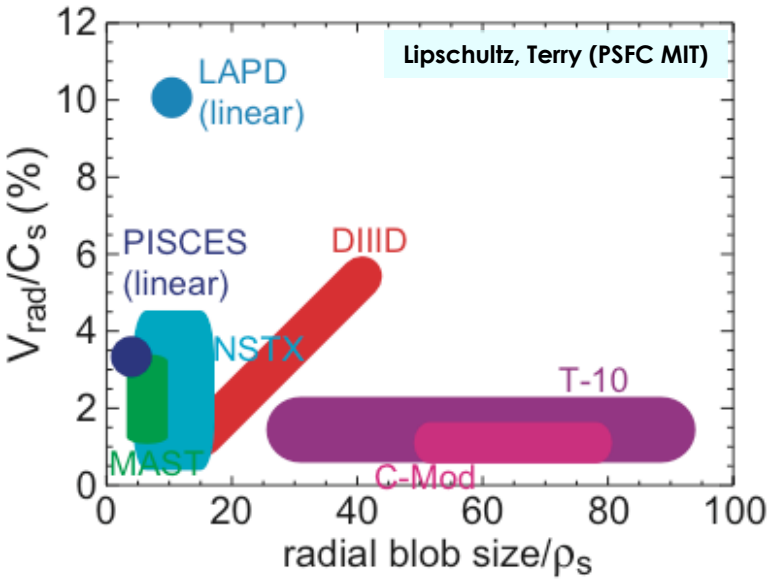
Plan for FY 2007 - 2008

- Further development of radiative and dissipative divertor for **high κ, δ CTF-relevant plasmas** using D_2 and CD_4, N_2 injection

Soukhanovskii PSI 2006, IAEA 2006

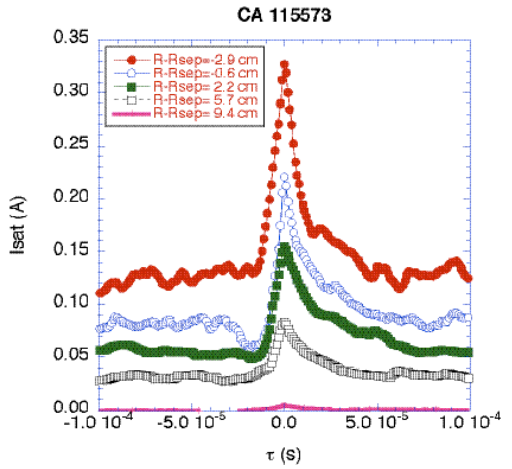
NSTX is at forefront of edge turbulence research

- **PAC-19 encouraged further edge T&T experiments and model development**
- **ITPA DSOL-15 - Multi-machine scaling of blob characteristics**



2005-2006 experimental results

- Filament structure and motion analysis from GPI and fast reciprocating probe (strongly endorsed by PAC-19)
- Blob velocity field analysis
- Void structure and motion analysis
- L-H transition studies, Reynolds stress and bycoherency (encouraged by PAC-19)
- Edge turbulence characteristics dependence on shape, density and collisionality (PAC-19)

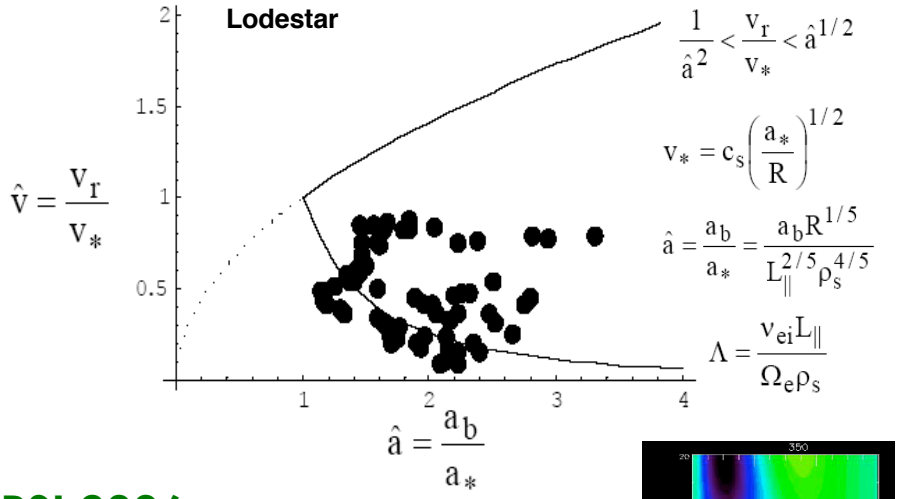


Boedo, Maqueda, Myra IAEA 2006; Zweben, White PoP 2006

Edge turbulence measurements with GPI and reciprocating edge probe help develop theory

Progress in edge turbulence theory and modeling

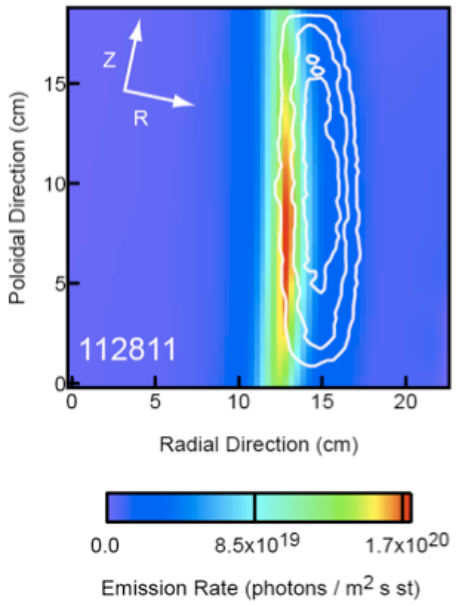
- "Blob" analytic theory
- BOUT edge turbulence modeling
- DEGAS-2 synthetic diagnostics
- XGC modeling



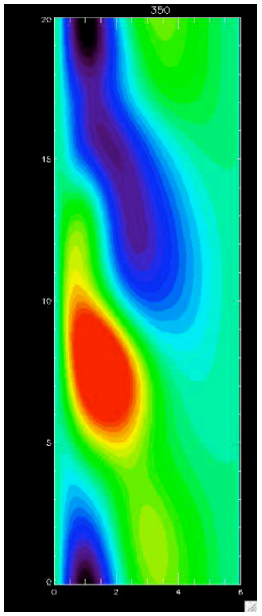
Myra IAEA 2006; Umansky APS 2006; Stotler PSI 2006

Plan for FY 2007-2008:

- Documentation of blob characteristics vs density, power, magnetic configuration for DSOL-15
- Turbulence characterization in H-mode
- Further data analysis and modeling



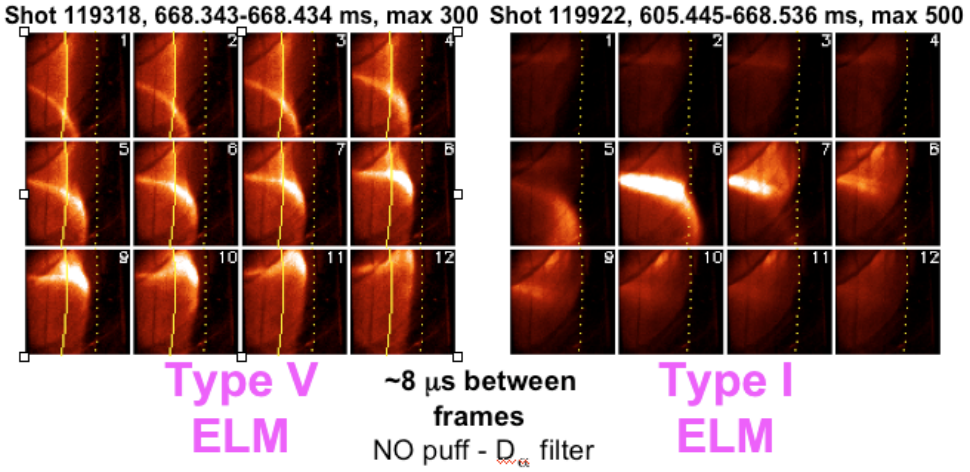
DEGAS 2 simulation of GPI diagnostic



edge n_e "blobs"from BOUT run for NSTX (LLNL)

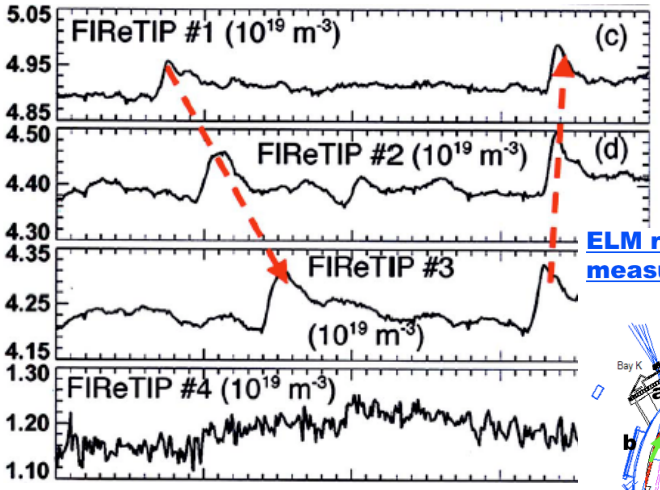
ELM structure, stability and parameter space studies are focus of NSTX research

- **PAC-19: study small and large ELM operational space**
- **ITPA PEP-16: Small ELM regime in NSTX, Alcator C-Mod and MAST**
- **NSTX well positioned to study ELMs**

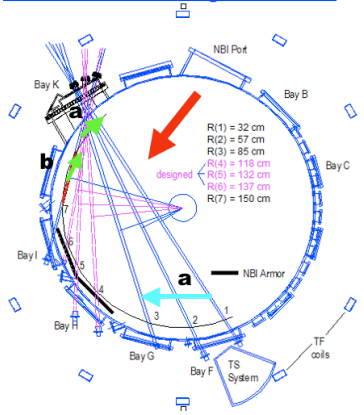


2006 Results

- Type I ELM structure and impact
- Type V ELM rotate counter-current with increasing tor. velocity
- ELM stability dependence on magnetic configuration, pedestal parameters



ELM rotation measurement by FIReTIP



Plan for FY 2007-2008

- Complete ITPA PEP-16 experiment (FY07 highest priority)
- All-diagnostic Type I and Type V ELM characterization

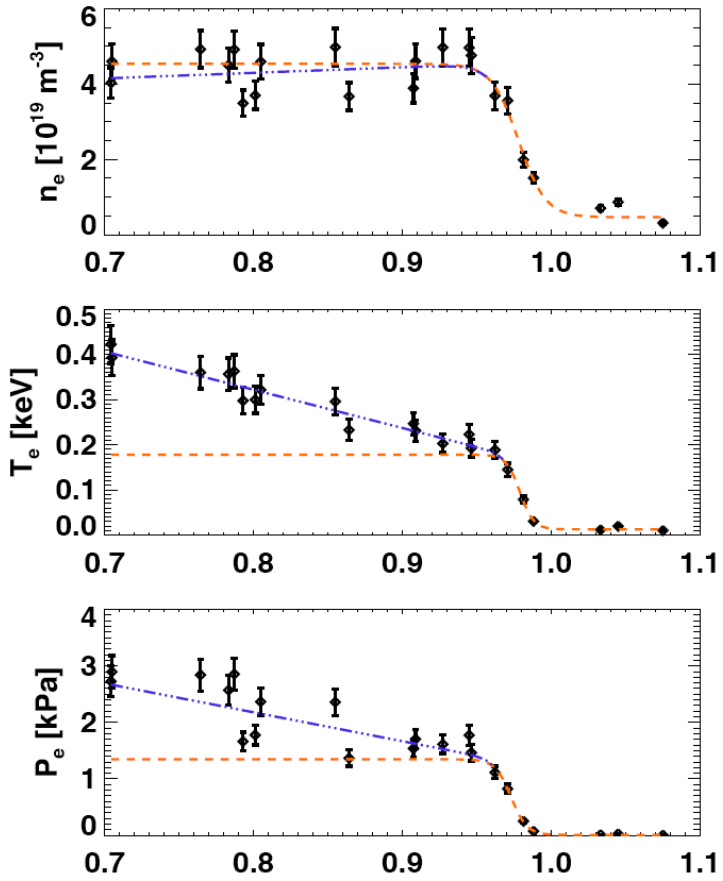
Maingi PoP 2006; Maqueda PSI 2006; Boedo IAEA 2006; Tritz APS 2006

Unique EPH-mode identified; Pedestal structure and stability vs toroidicity are studied

- **PAC-19: "very interesting" - good idea to pursue EPH-mode studies**
- **ITPA PEP-9: Dependence of pedestal structure on aspect ratio**

2005-2006 Results

- **30-point MPTS now available**
- **EPH-mode:** H89P ~ 2.6-2.7, $T_{e,i\,ped}$ ~ 650 eV (c.f. 100-300 eV for H-mode), P_{th}~2-4 MW, large v_ϕ gradient
- **Pedestal structure dependence on toroidicity:**
  - Comparable shape achieved in all machines
  - DIII-D pedestal appears wider than MAST and NSTX with similar collisionalities
  - NSTX appears to have higher pressure gradient



Plan for FY 2007-2008

- Complete PEP-9 experiment
- Study EPH-mode (in ISD group)

Maingi IAEA 2006; Maingi APS 2006

Material migration studies help understand particle and dust sources and transport

- **ITPA DSOL-17: Cross-machine comparison of pulse-by-pulse deposition**

2006 Results

- Stereoscopic dust trajectory measurements demonstrated
- Quartz microbalance results:
  - Mass gain / loss at measured rate over ~10% of the vessel area can account for D fueled and pumped.
  - Long term erosion / deposition small compared to dynamic retention

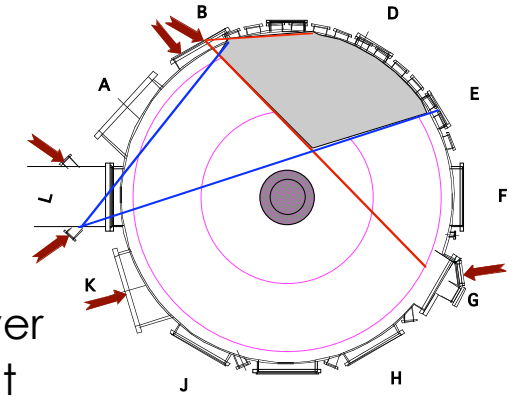
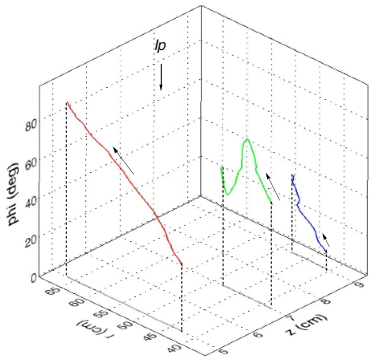
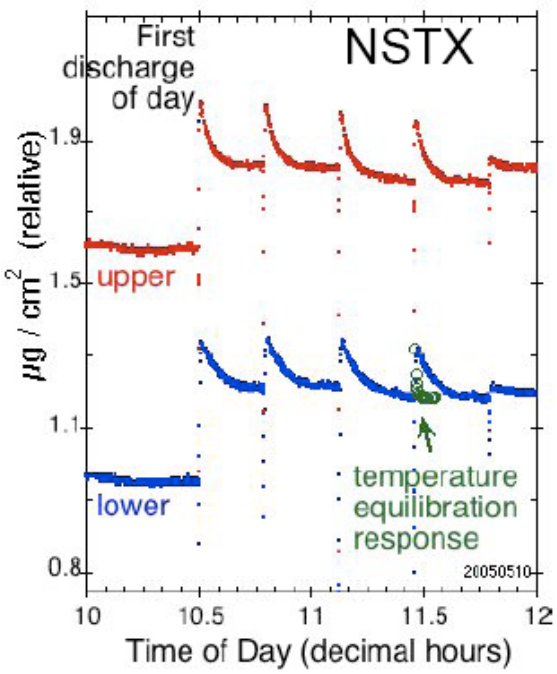


Fig 1a.



Plan for FY 2007-2008

- Install and commission hypervelocity dust injector
- DUSTT code benchmarking
- Study material migration vs pulse length and shape
- Support lithium experiments
- Continue DSOL-17 experiment (JET, ASDEX)



Skinner, Pigarov PSI 2006; Skinner, Roquemore APS 2006

Highest priority in 2007 is given to the lithium, milestone-related, and ITPA experiments

Mile-stone	ITER / ITPA	ST phys.

- **Lithium experiments**
  - Injection and Dispersion of Li powder for Improvement of H-Mode
  - Investigate Effect of Lithium on H-Mode Performance with LPI
  - Investigate Effect of Lithium-Coated Divertor on Plasma Performance with LITER-1d

✓ FY 2009 incremental

- **Comparison of Small ELM Regimes in Alcator C-MOD, MAST, and NSTX**

✓ ✓

- **SOL width scaling**

✓ FY 2008 ✓

- **Dependence of Pedestal Structure on Aspect Ratio**

✓ ✓

High priority in 2007-2008 is given to turbulence, ELM, radiative divertor, fueling and dust experiments

Mile-stone	ITER / ITPA	ST phys.

- **Edge turbulence characterization**
  - "Testing Theory on Blob transport-Blob velocity, Holes and Blob size, Intermittency… "
  - "Edge Turbulence and Blobs During H-mode"
  - "Characterization of Blobs/filaments on NSTX in Support of ITPA Research Task DSOL-15 - Multi-Machine Scaling of Blob Characteristics"
- **Divertor heat flux reduction and detachment**
- **Electrode Biasing for SOL Control**
- **ELM characterization experiment**
  - "Characterization of Interaction of ELMs with NSTX Edge/Divertor using Fixed Langmuir Probes"
  - "Type V ELM Rotation and Toroidal Origin"
  - "Multi-diagnostic ELM Characterization"
  - "ELM Character vs. Collisionality XP"
- **Dust particle Injection for Benchmarking the DUSTT Code**
- **MARFE characteristics**
  - "MARFE Space in NSTX"
  - "Hot Electron Component of the MARFE"
- **High-pressure Supersonic Gas Jet Fueling (SGI-Upgrade)**
- **Dependence of ELMs and Power Balance on Magnetic Balance and Fueling**

FY 2008

Back-up slides

Boundary Physics diagnostics in FY07