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Overview of the NSTX 2007 Run

presented by

David Gates

For the NSTX Team

at

NSTX PAC-23

January 22-24, 2008

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
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MIT
Nova Photonics
New York U
Old Dominion U
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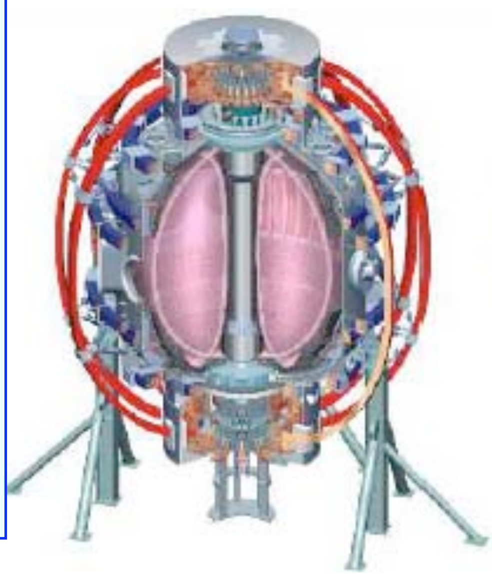
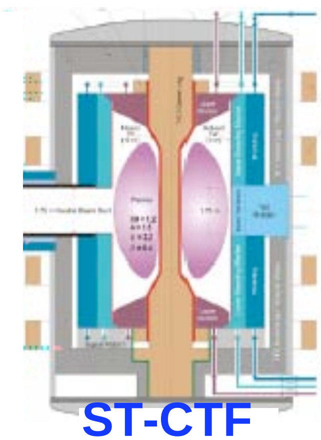


Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NSTX run plan is motivated by the Next Steps in the ST Development Path

NHTX in the 3 - 4 MA range provides cost effective physics / technology basis in support for CTF and DEMO: Demonstrate stable continuous high-performance operation with very high heat flux and acceptable hydrogen isotope retention.



Compact ST-CTF at ~ 10 MA range provide a compact nuclear component test facility to support DEMO: Provide ~ 6 MWyr/m^2 neutron over ~ 10 m^2 with acceptable level of tritium consumption

Activities are organized by Experimental Task Groups

- Run priorities set in 2007 NSTX Research Forum
  - Including input from PAC-21
  - ITPA tasks and milestones increase experimental priority
- NSTX performed 43 Experimental Proposals & 4 Machine proposals
  - ST development (100%)
  - Milestone related research (25%)
  - ITPA tasks (30%)
- Enabling tasks
  - Machine startup
  - RF conditioning
  - CHI commissioning
  - MSE calibration

Task Group	Run days	Milestones and ITPA tasks	
MHD and Energetic Particle Physics	16.7 days	2	5
Transport and Turbulence	11.8 days	1	6
Boundary Physics	9.7 days		5
Solenoid Free Startup	4.8 days		-
Waves	5.5 days		-
Integrated Scenario Development	9.5 days		2
Enabling Activities	5.0 days		
Total	63.1 days		

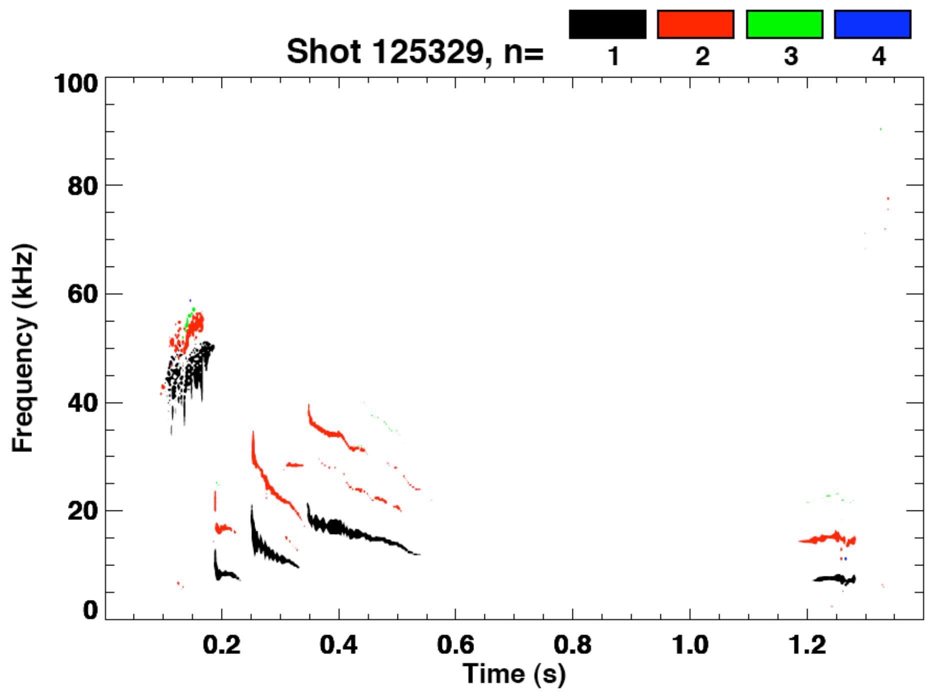
Activities are organized by Experimental Task Groups

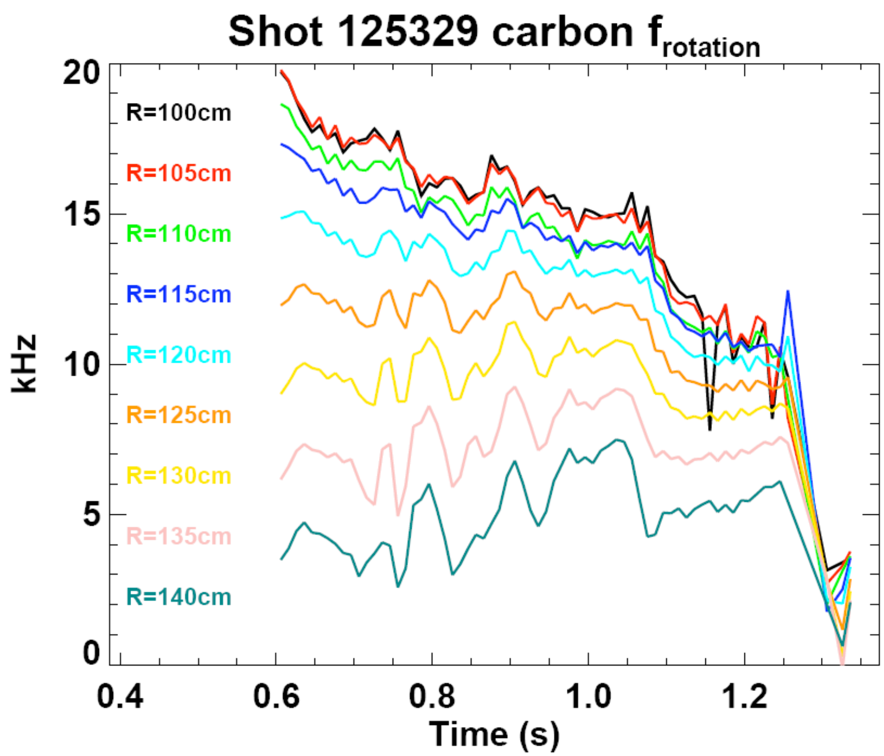
- MHD and Energetic Particle Physics
- Transport and Turbulence
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

Milestone R(07-2)
Combined RWM and error field control extend pulse and maintain plasma rotation

- RWM feedback demonstrated in 2006 (APS invited, PRL -2006, Sabbagh)
- NSTX has demonstrated the utility of non-axisymmetric control in maintaining plasma performance 2007 APS Invited, Menard
- Combined feedback control of RFA and static n=3 error field correction maintains edge rotation *(Ph.D. thesis)*
  - Long MHD free period
  - Record pulse length at 900kA (~1.25s)

- *PAC-21-4*
- *ITPA - MDC-2*





Tearing mode experiments find β_N threshold for onset of 2/1 NTM decreases as rotation decreases

- 30% reduction in β is qualitatively consistent with DIII-D results (& JET)

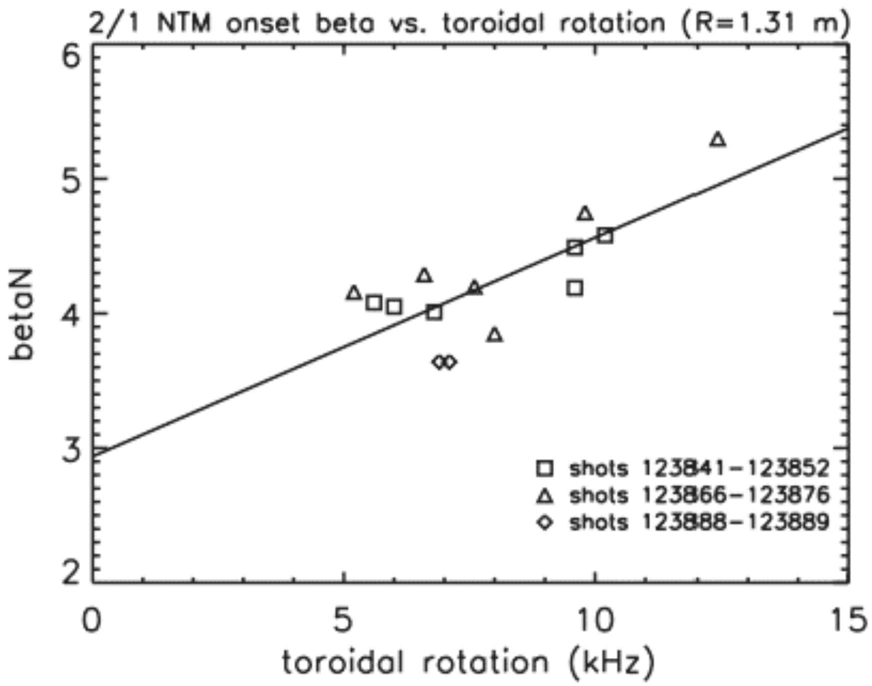
→ Impact of rotation on NTM stability is broad result vs. aspect ratio and β

  - **Important implications for ITER which is expected to have low rotation**
  - **Highlights advantage of $q_{min} > 2$**

- NHTX and ST-CTF with unidirectional tangential NBI may be relatively immune to NTM
- NHTX and ST-CTF also predicted to have similar ρ*, higher NTM polarization threshold?

$$a_{pol} \propto \rho_{i\theta}^2 \; g(\nu,\varepsilon) \; \omega \, (\omega_{i*} - \omega)/\omega_{e*}^2$$

n=3 non-resonant magnetic braking used to control rotation



- *PAC-21 - 4*
- *ITPA-MDC-3,4*

Joule Milestone R(07-3)

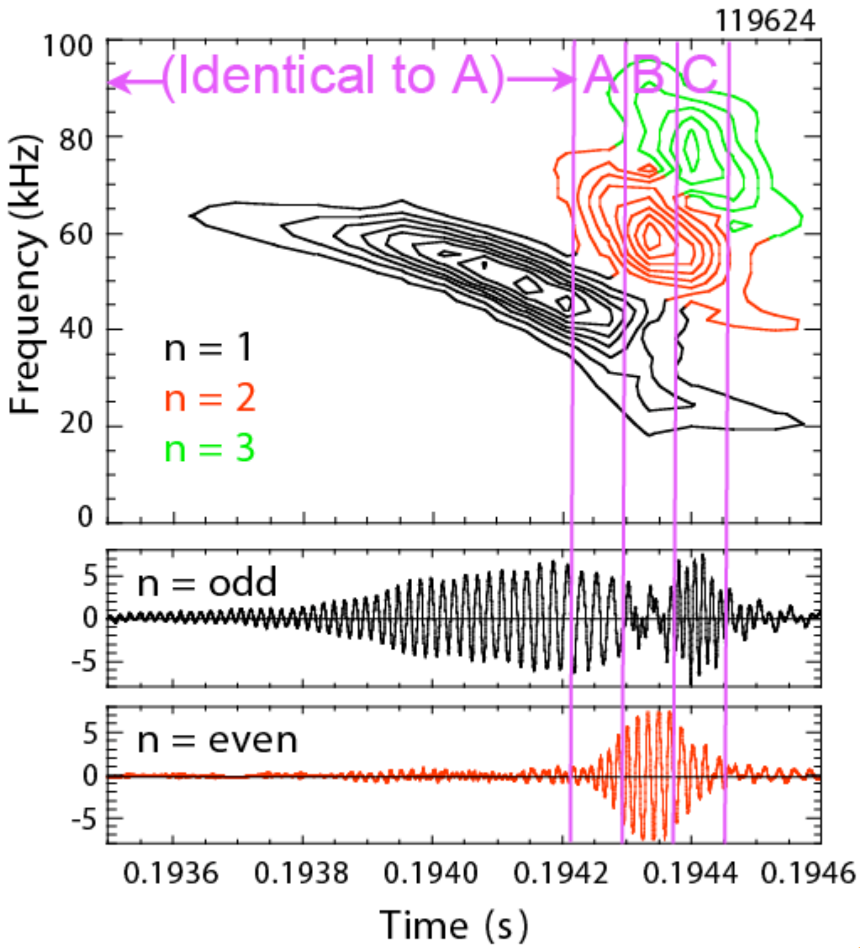
NSTX has measured, identified and characterized several modes driven by super-Alfvénic ions

- Using NBI power and voltage scans the full range of TAE behavior - from quiescence to avalanche - has been documented which is important for ITER and future STs
  - Extensive array of fast ion diagnostics
    - NPA, SFLIP, SSNPA, FIDA (prototype), neutrons
  - Current profile measured with MSE
- Alfvén cascades observed and predicted q_{min} agrees with MSE measurements
- Coupling of cascades observed during β -scan to Geodesic Acoustic Modes as predicted by theory
- New mode observed - β-induced Alfvén Acoustic Mode

- *PAC-21 - 7,8,10*

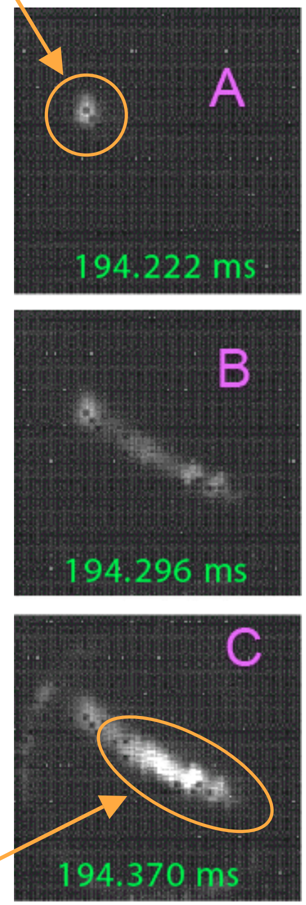
Fast Ion Loss of from Multiple Nonlinearly Interacting Modes Measured and Simulation Effort is Underway

Prompt loss of 90keV D⁺

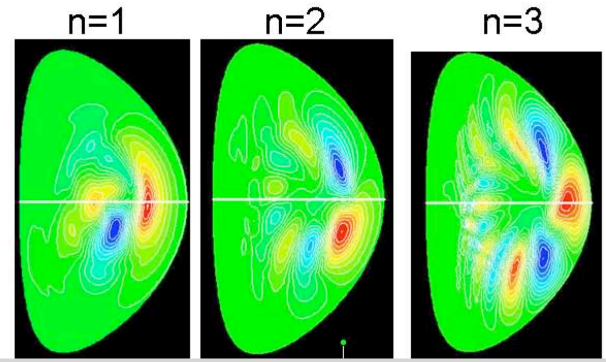


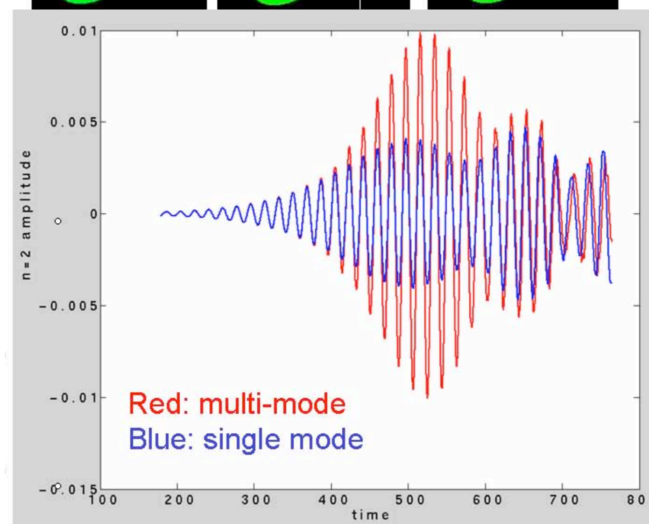
Mode-induced loss of 90keV D⁺

Fast Lost Ion Probe



M3D simulations of non-linear mode-mode interactions can impact mode amplitudes

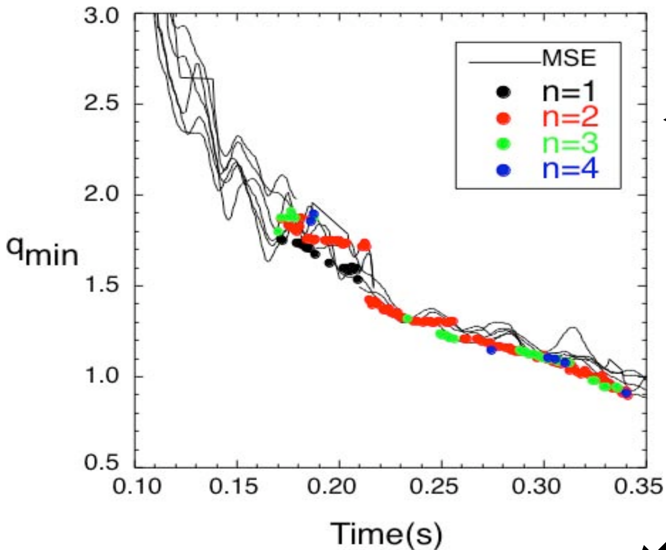




<u>n=2 amplitude:</u> *multi-mode amplitude higher than for single mode treatment*

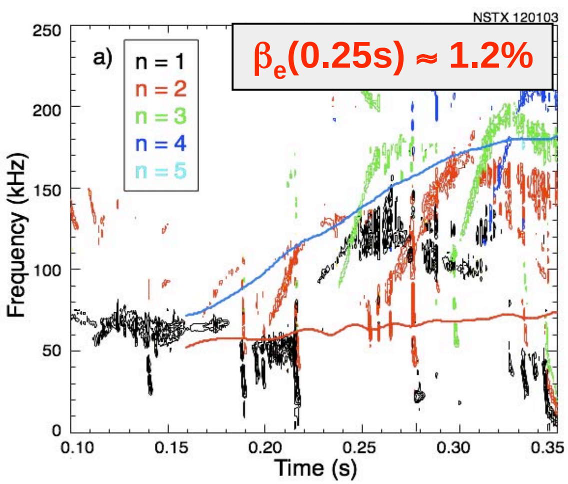
2007 APS Invited, Fu

NSTX observations support recent theoretical models of Alfvén Cascade modes coupling to Geodesic Acoustic Modes

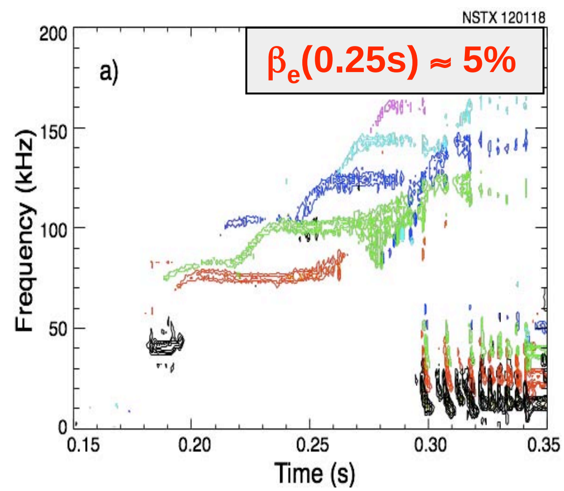


- MSE data agrees with q_{min} deduced from mode frequency sweeps
- Range of frequency sweep is reduced as β is raised, in agreement with theory
- Mode frequency evolution:
  - Onset near GAM frequency (lower red curve)
  - Frequency sweeps upwards
  - Saturates near TAE frequency (blue curve)

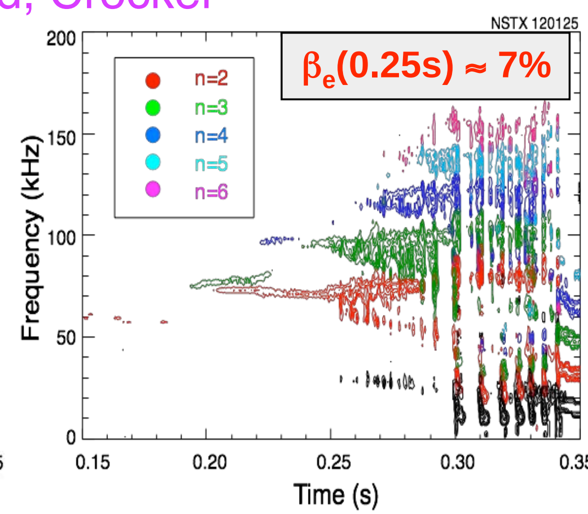
2007 APS Invited, Crocker



Largest frequency sweep



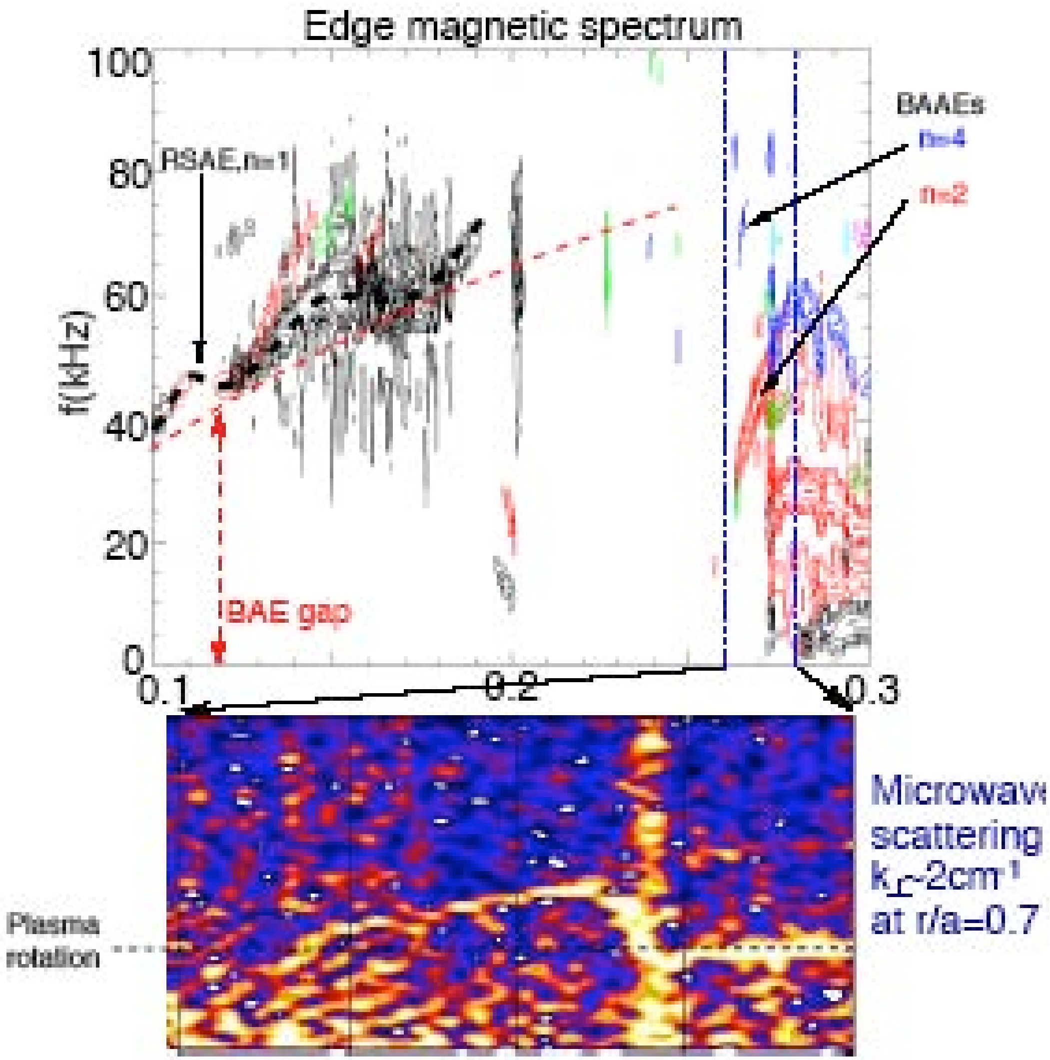
Frequency sweeps reduced



Frequency sweeps absent

β scan demonstrating AC/GAM coupling is first of its kind

Beta-induced Alfvén-Acoustic Eigenmodes
New global MHD eigenmode found at high beta



- **Beta-induced Alfvén-Acoustic Eigenmodes or BAAE found below the geodesic acoustic mode (GAM) frequency in gaps in the low frequency Alfvén - acoustic continuum.**

- **These new eigenmodes can explain observations of modes with frequencies well below the TAE frequency in NSTX**

Conversion to short wavelength kinetic Alfvén waves observed with high-k scattering

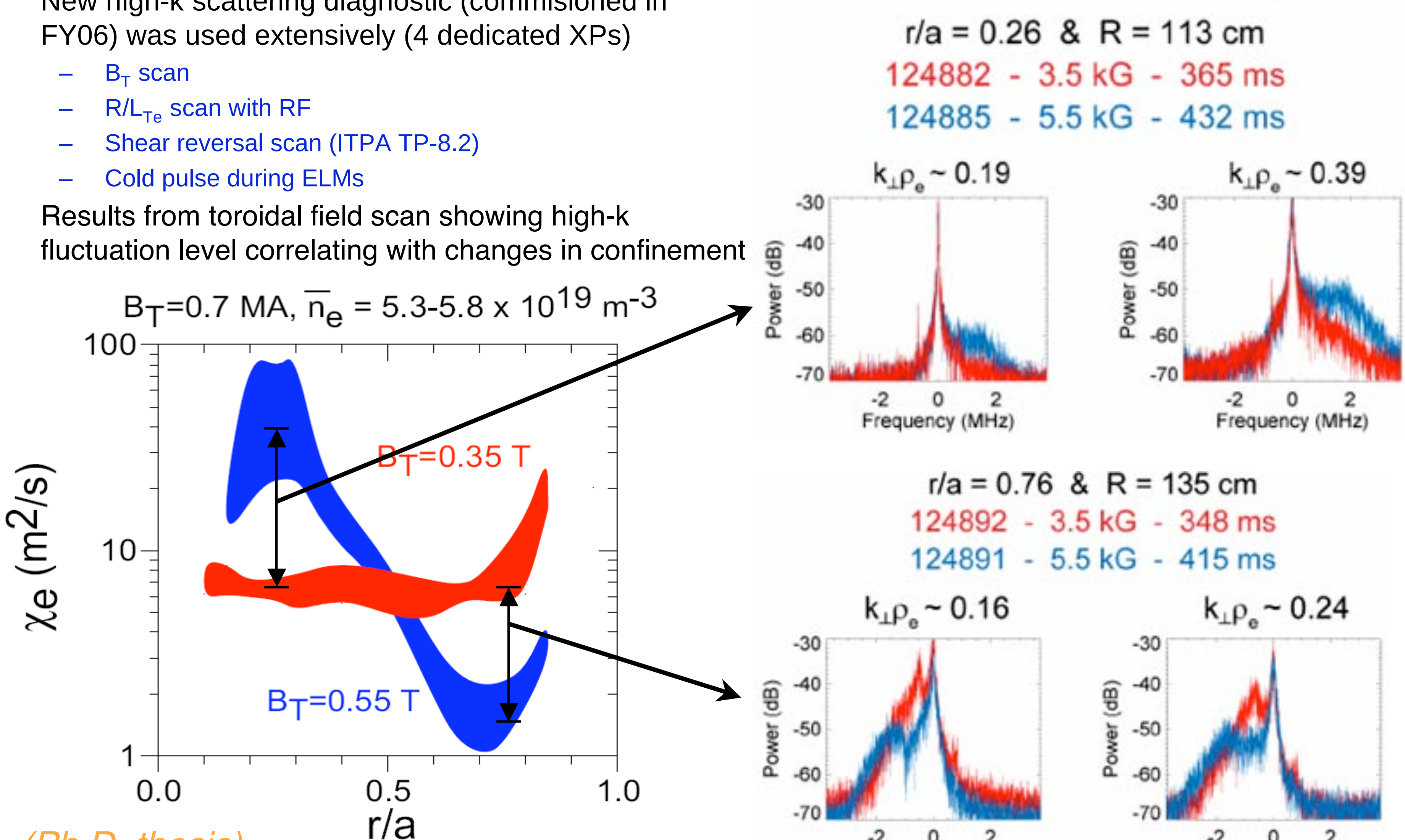
- *PAC-21 - 10*

Activities are organized by Experimental Task Groups

- MHD and Energetic Particle Physics
- Transport and Turbulence
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

Milestone R(07-1)
Study variation of local high-k turbulence with plasma conditions

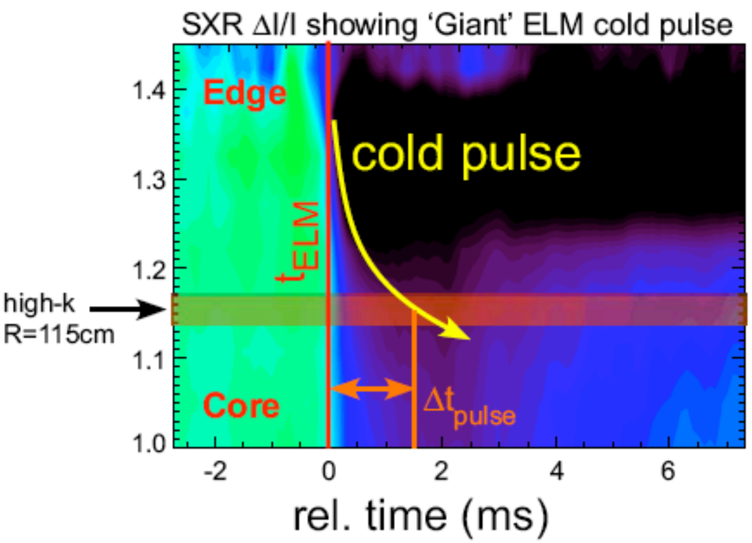
- New high-k scattering diagnostic (commisioned in FY06) was used extensively (4 dedicated XPs)
  - B_T scan
  - R/L_{Te} scan with RF
  - Shear reversal scan (ITPA TP-8.2)
  - Cold pulse during ELMs
- Results from toroidal field scan showing high-k fluctuation level correlating with changes in confinement

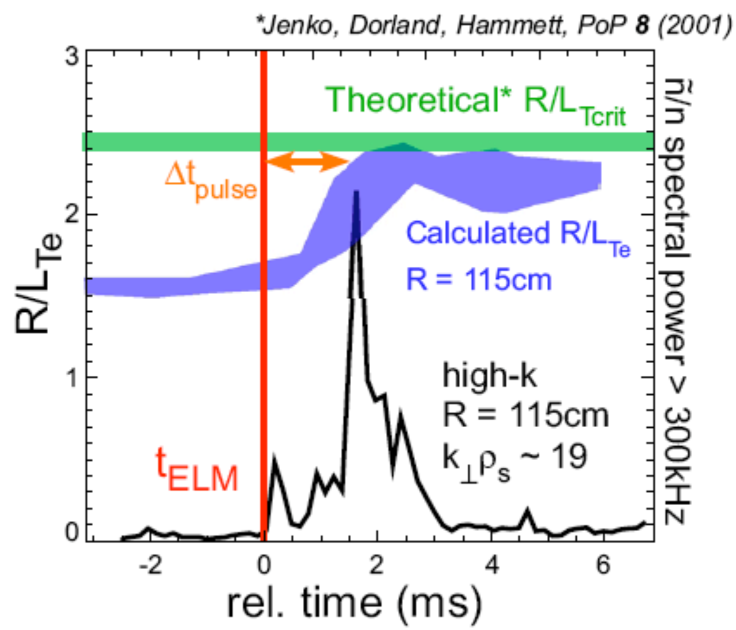


(Ph.D. thesis)

High-k scattering measures enhanced turbulent fluctuations during ELM "cold-pulse"

2007 APS Invited, Tritz

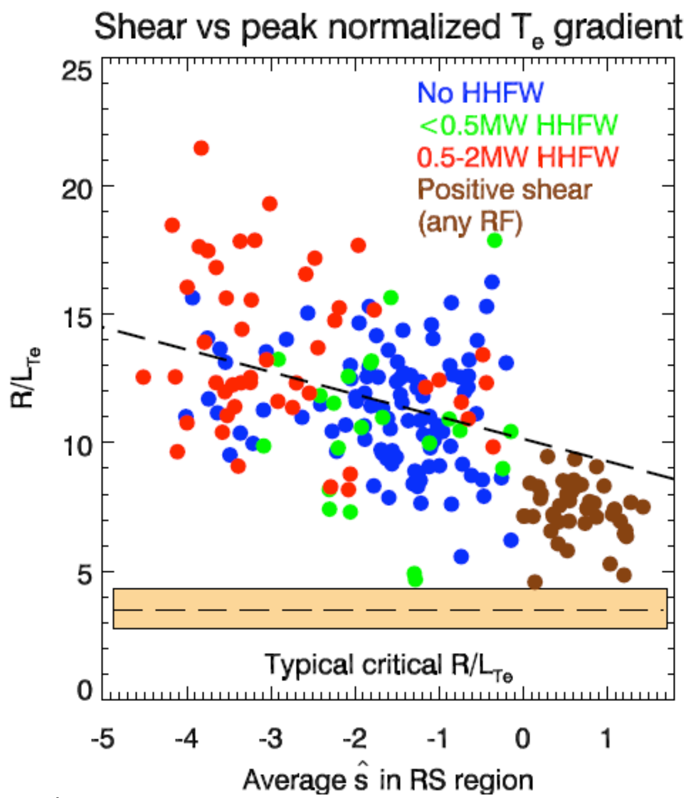


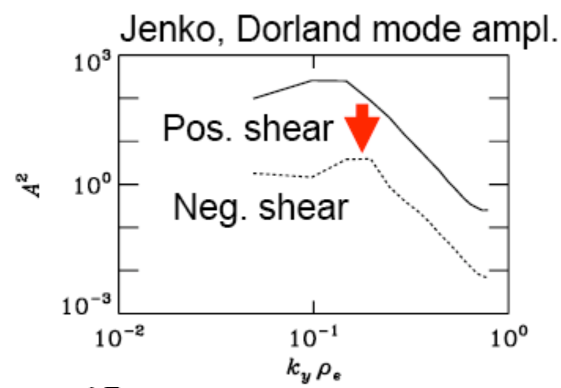


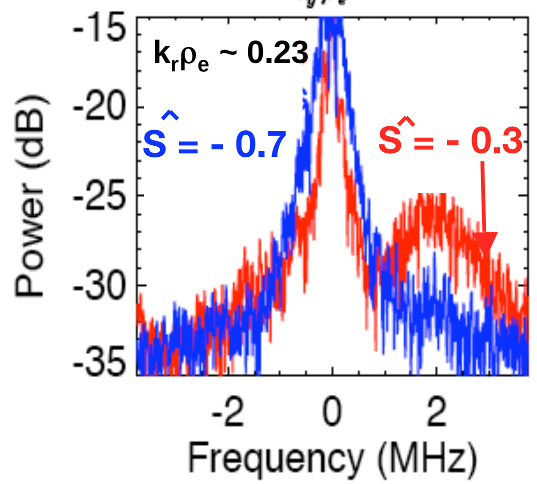
- Low steady-state T_e gradient in core suggests stable ETG
- Core high-k measurements show increased fluctuations during 'Giant' ELM cold pulse
- Cold pulse increases T_e gradient during core propagation
  - $R/L_{Te} \Rightarrow R/L_{Tcrit}$ supports ETG destabilization
  - Jenko et al. approximation validated by GS2 R/L_{Tcrit} calculation

Reverse shear discharges show

- Electron ITB location strongly correlated with minima of negative magnetic shear
- Measured suggestive changes in high-k fluctuations with deepened shear reversal
- Turbulence suppression is in a narrow band of k near predicted most unstable ETG



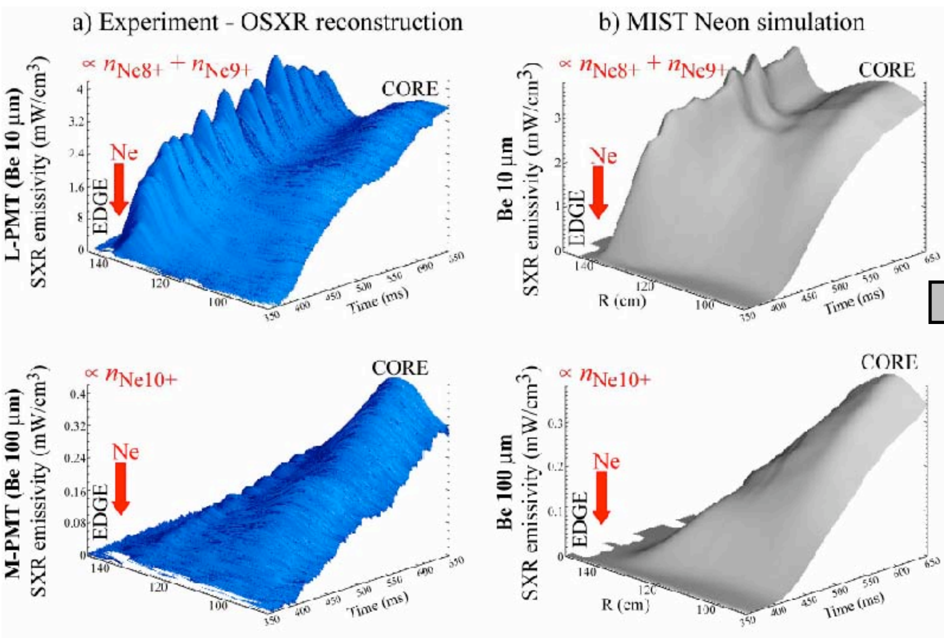


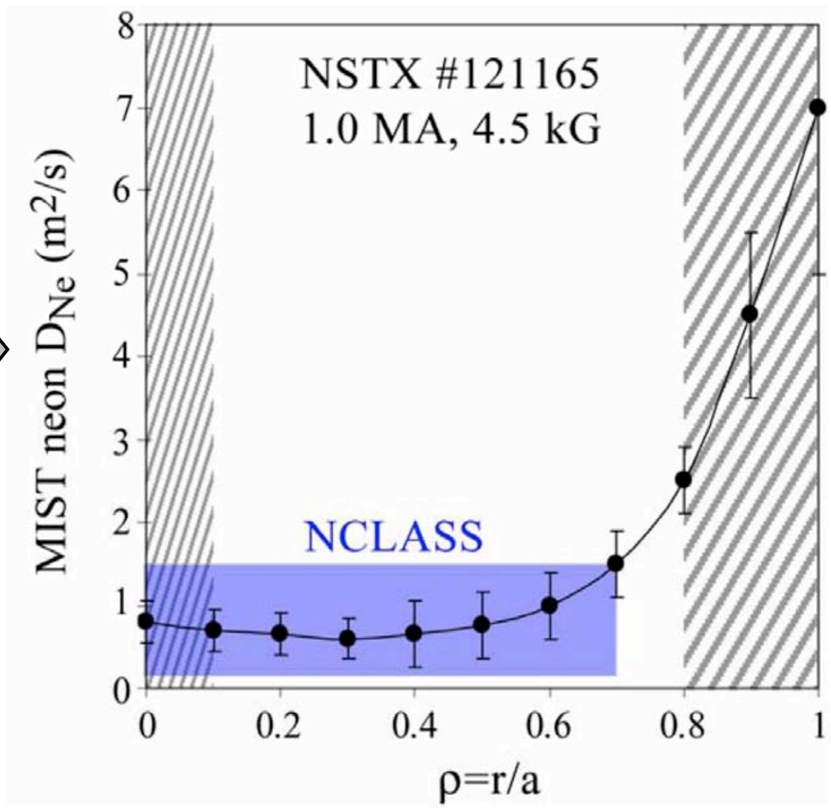


Impurity transport studies confirm impurity ion particle transport near neoclassical over most of profile in H-mode

- New multi-color "optical" SXR tracks inward transport of Ne impurities
- MIST transport simulations yield particle diffusivity and v_{pinch}
- Extends previous L-mode results

(Ph.D. thesis – JHU)





Small inward particle pinch (~few m/s) required for agreement

- *PAC21-2*

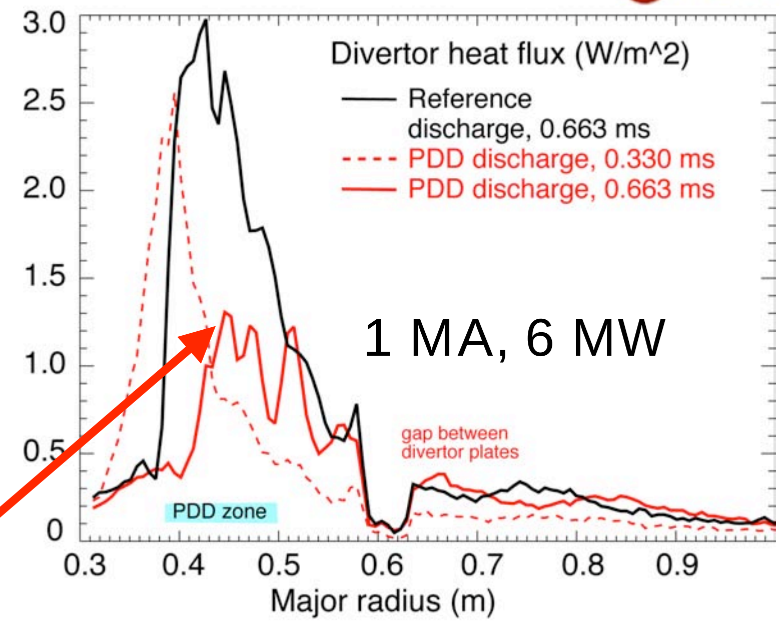
Activities are organized by Experimental Task Groups

- MHD and Energetic Particle Physics
- Transport and Turbulence
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

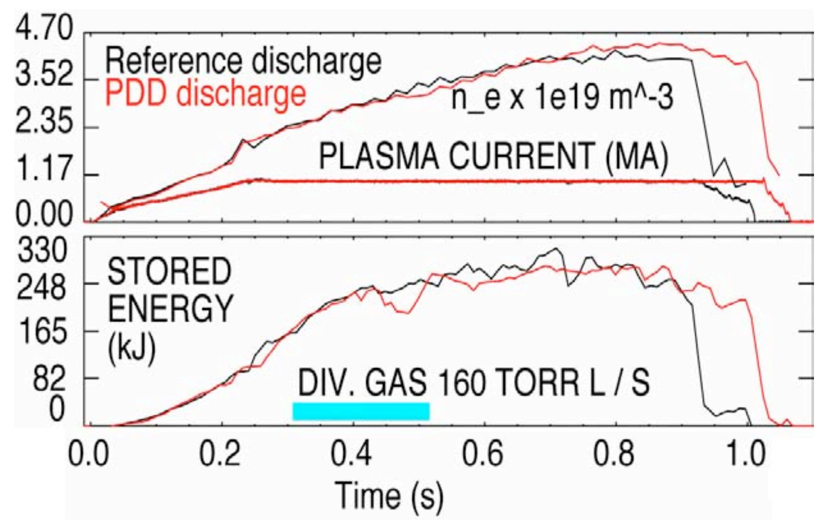
Partially Detached Divertor (PDD) achieves significant heat flux reduction at high κ, δ with no decrease in H-mode confinement

Extended results from low κ, δ (2006) to high κ, δ, high flux expansion shape for high performance scenarios

2007 APS Invited, Soukhanovskii

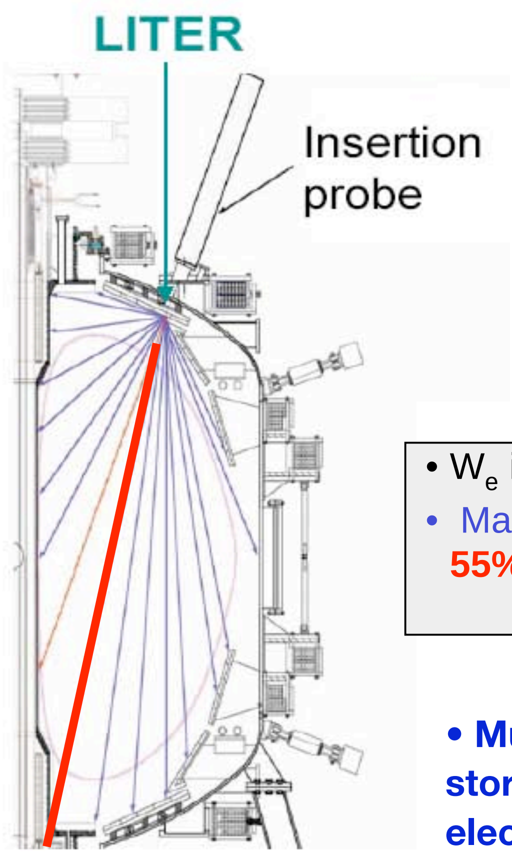


- Peak divertor heat flux **reduced by factor 2-3× during PDD phase** by injecting D_2 in divertor
- No increase in main plasma density
- No degradation of confinement
  - Same W_{TOT} for same P_{NBI} = 6MW



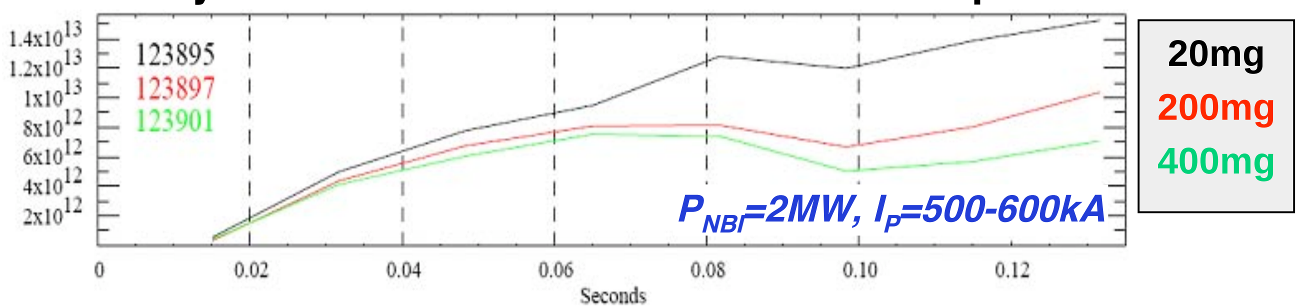
Heat flux mitigation techniques compatible with high performance crucial for next-steps

Lithium Evaporator (LITER) improves energy confinement time



2nd LITER for complete toroidal coverage for 2008

Density decreases with increased Lithium deposition

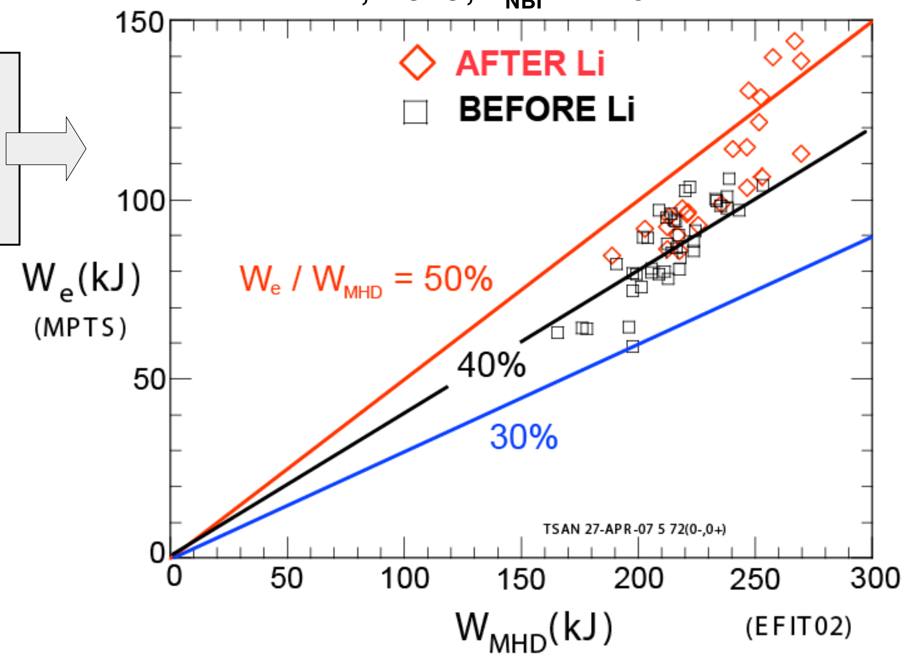


- W_e increases up to 40%
- Max. (W_e / W_{MHD}) = 45% → 55%

- **Much of increase in stored energy comes from electrons (broader Te)**
- **Edge hydrogenic neutral density and recycling also decreased**

(Ph.D. thesis)

1MA, 4.5kG, P_{NBI} = 4 ± 0.4MW



2007 APS Invited, Kugel

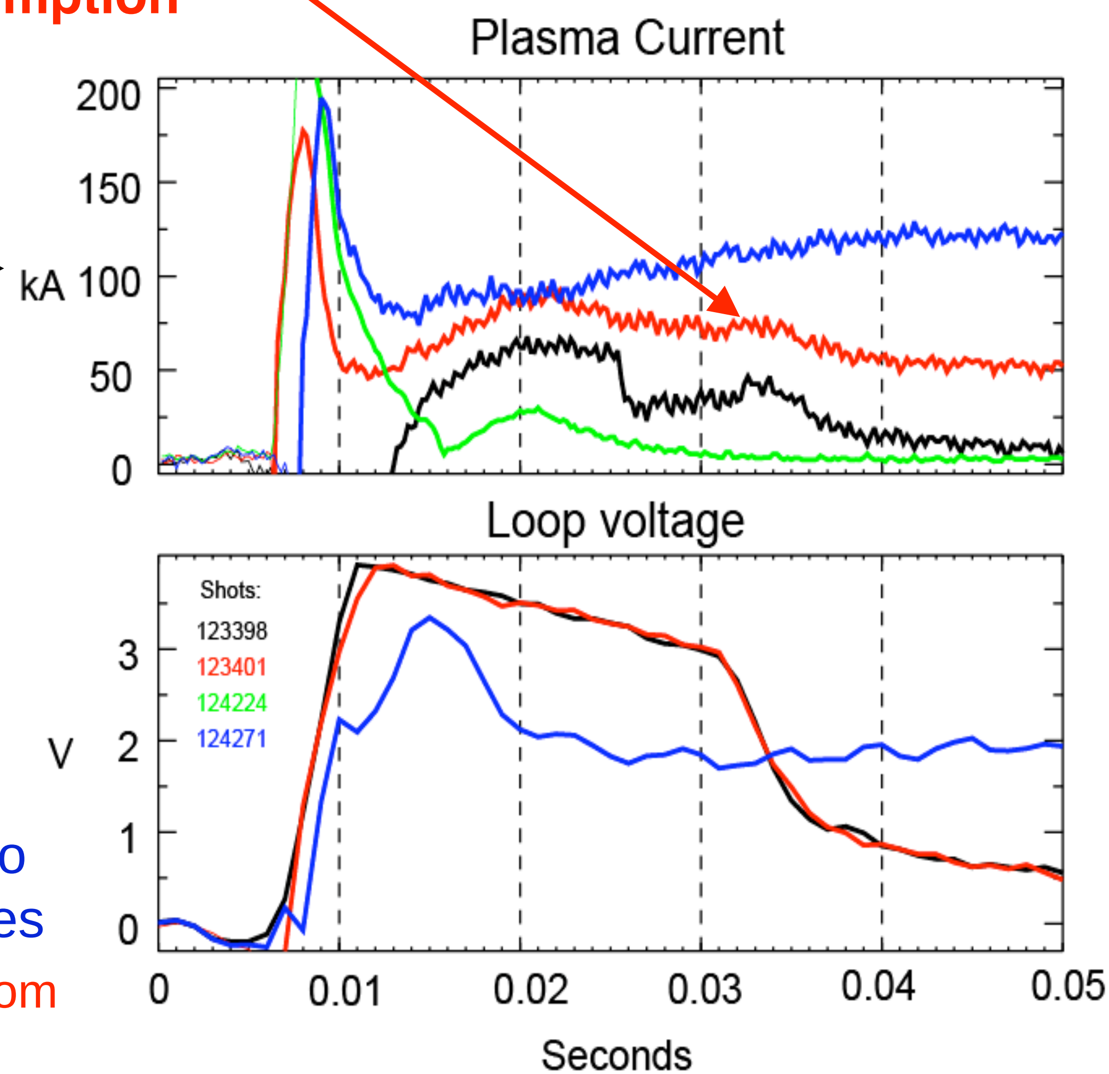
Activities are organized by Experimental Task Groups

- MHD and Energetic Particle Physics
- Transport and Turbulence
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

Coaxial Helicity Injection (CHI) plasmas successfully coupled to transformer induction in NSTX for first time

CHI can reduce OH flux consumption

CHI only
Induction only
CHI + induction
CHI + induction: I_P = 120kA
(Boronization + improved PF programming)



- FUTURE optimization:
  - LITER during CHI
    - stronger pumping
    - reduced impurities
  - Use flux savings from CHI to extend long-pulse discharges
    - Use pre-charged solenoid from standard OH I_P ramp

Activities are organized by Experimental Task Groups

- MHD and Energetic Particle Physics
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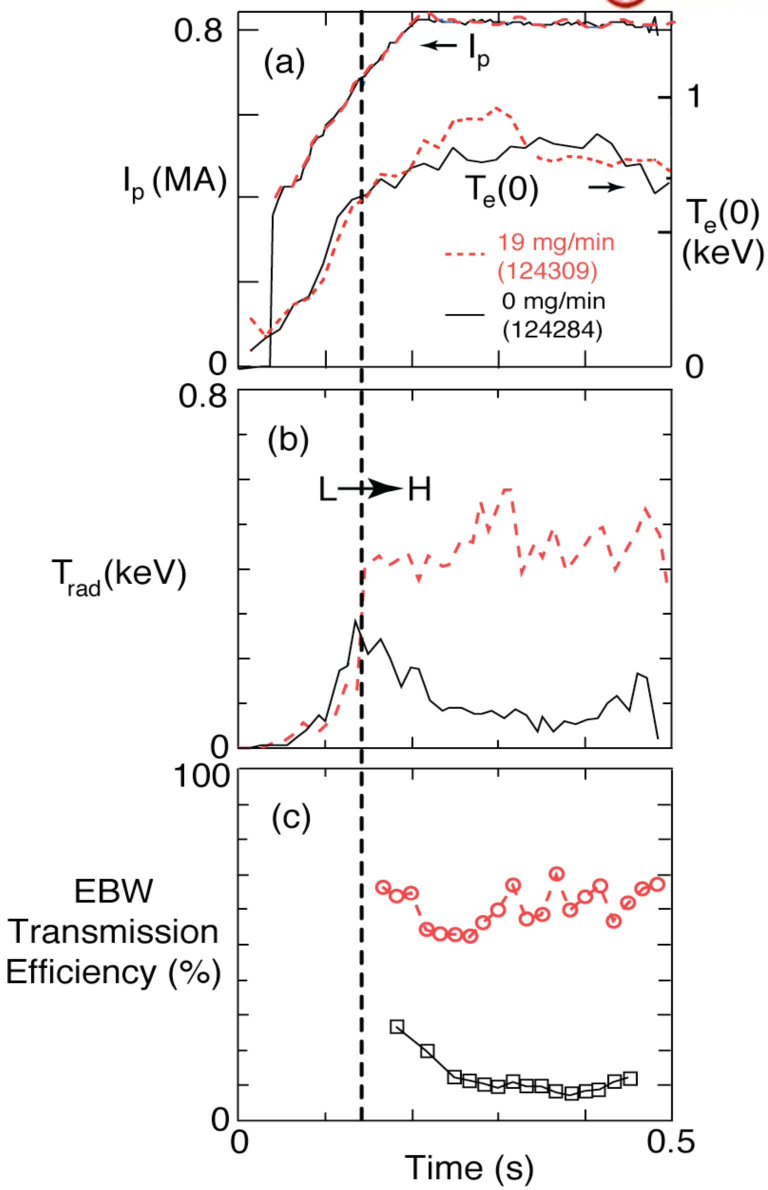
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

FY07 EBW experiments in H-mode provide insight into plasma parameters that may control B-X-O mode conversion efficiency

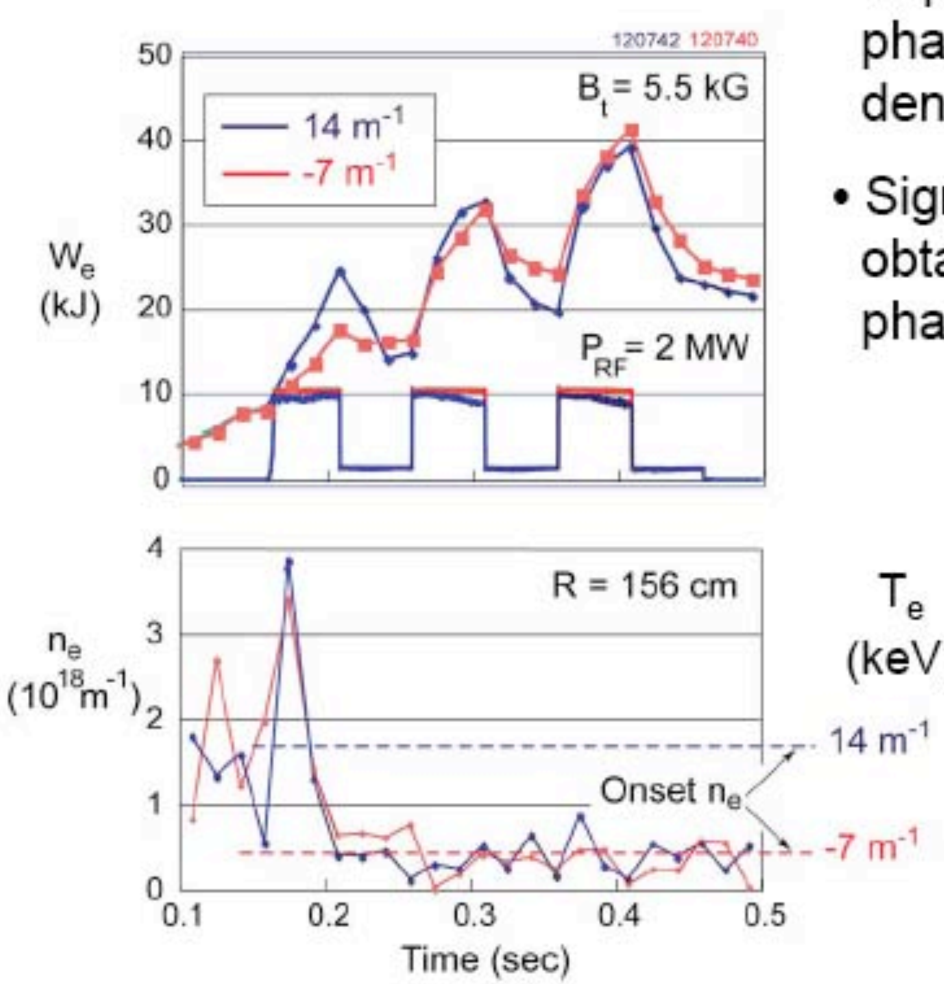
- Lithium reduces collisional damping in boundary, increasing transmission efficiency
- T_{rad} increases from ~50eV to ~450eV
  - Corresponding transmission efficiency increases from <10% to >60%
- Simulation predicts EBW collisional damping significant for T_e< 20 eV



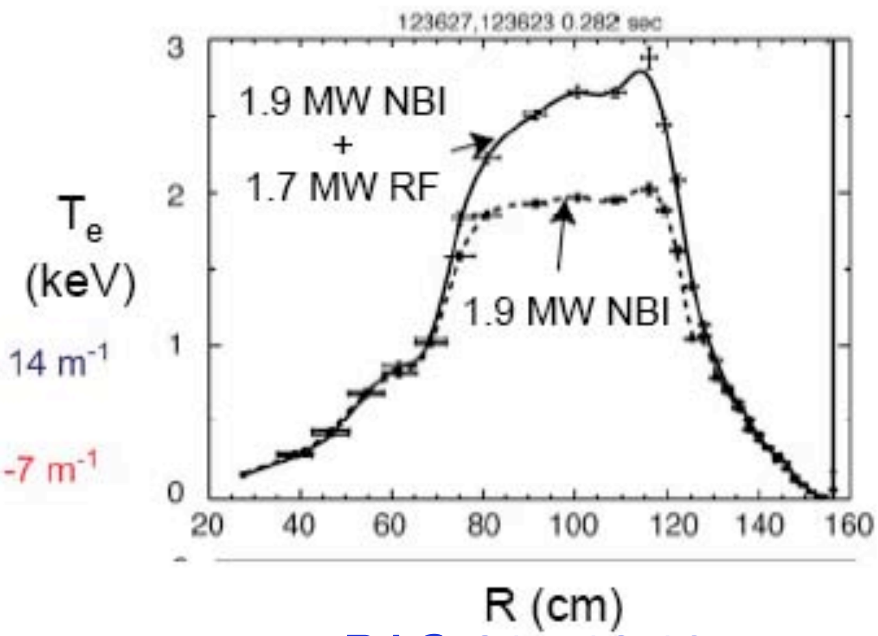
(Ph.D. thesis)

- *PAC-21 - 11*

HHFW Coupling is improved when density near the antenna is below surface wave onset



- Improved HHFW coupling for CD phasing obtained by lowering edge density **4.6 keV achieved with CD phase**
- Significant core electron heating now obtained in L-mode for CD antenna phasing during NBI at $B_t(0)$ = 5.5 kG



2007 APS Invited, Hosea

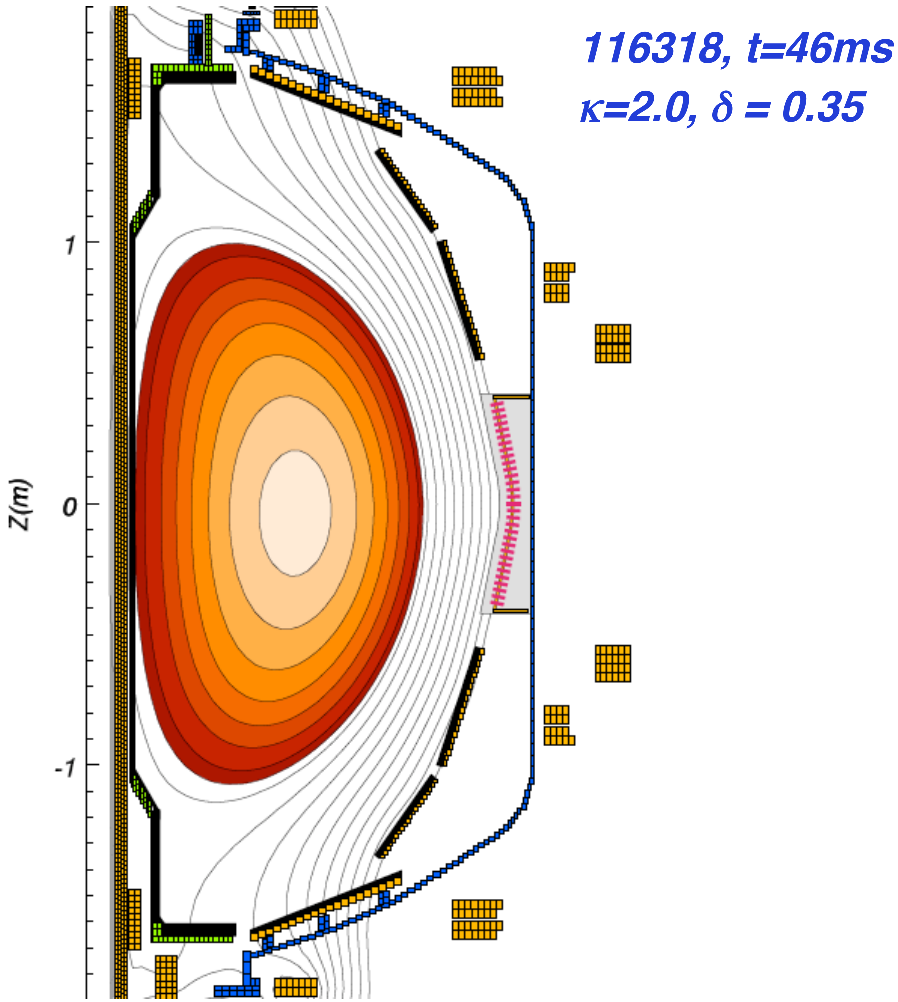
- *PAC-21 - 12,13*

Activities are organized by Experimental Task Groups

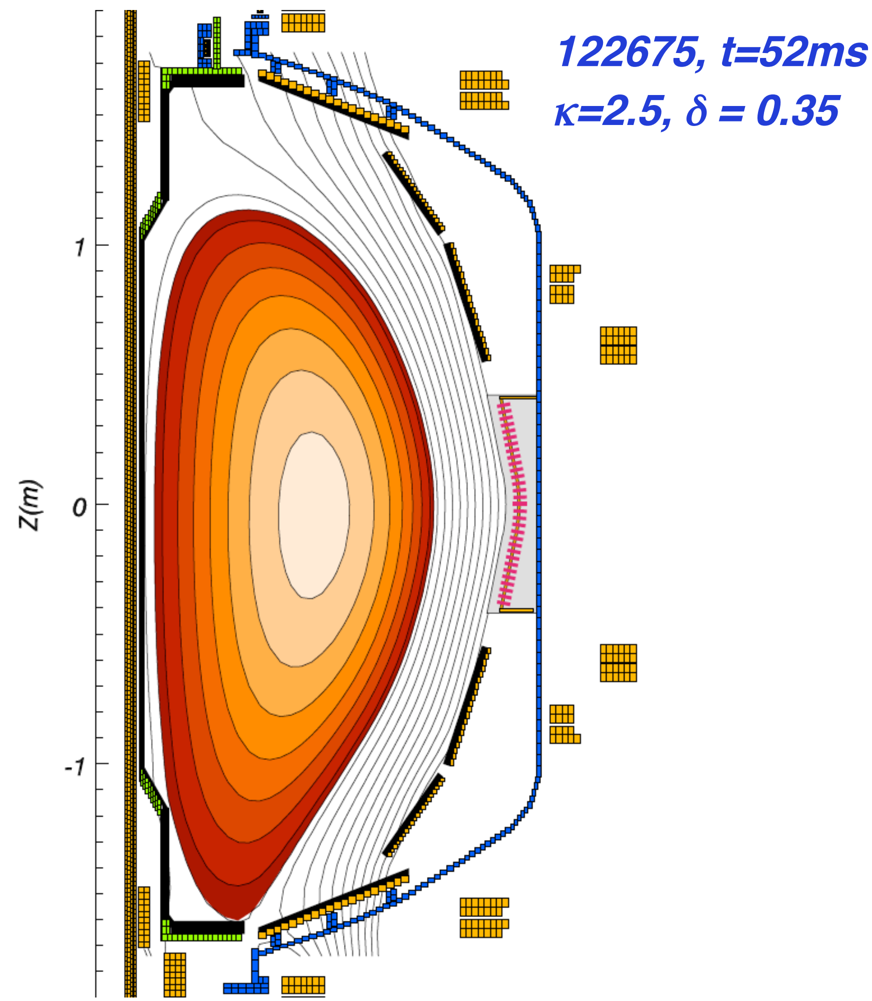
- MHD and Energetic Particle Physics
- Transport and Turbulence
- Boundary Physics
- Solenoid Free startup
- Wave Physics
- Integrated Scenario Development

Divertor coil current during break-down phase enables increased ramp-up elongation, very early diverting+H-mode → elevated *q*

- Plasma shape during I_P ramp with old breakdown



- Plasma shape w/ new breakdown

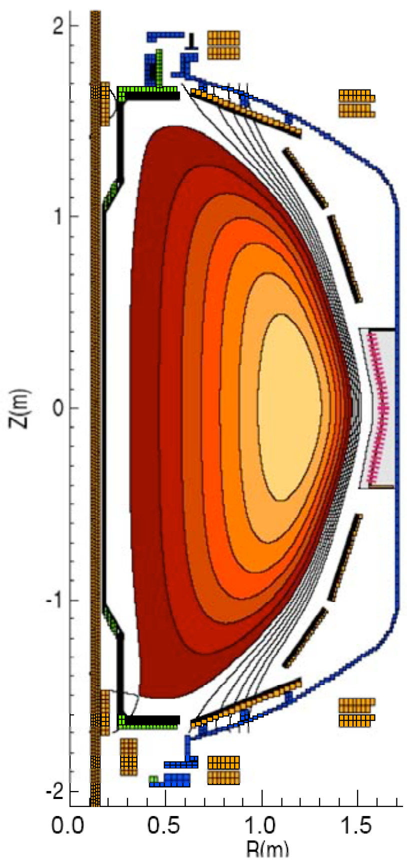


- *PAC-21 - 41*

rt-EFIT isoflux control algorithm achieves and maintains shape very close to desired target shape

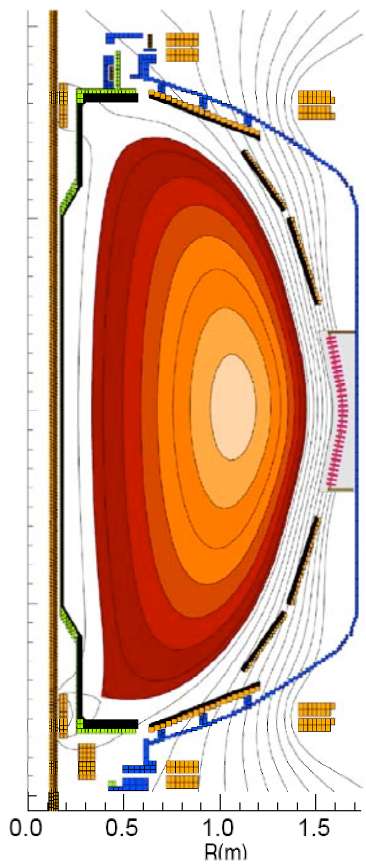
High q_{min} TARGET

κ= 2.6, δ_{X-L} = 0.85
δR_{SEP} = -2mm



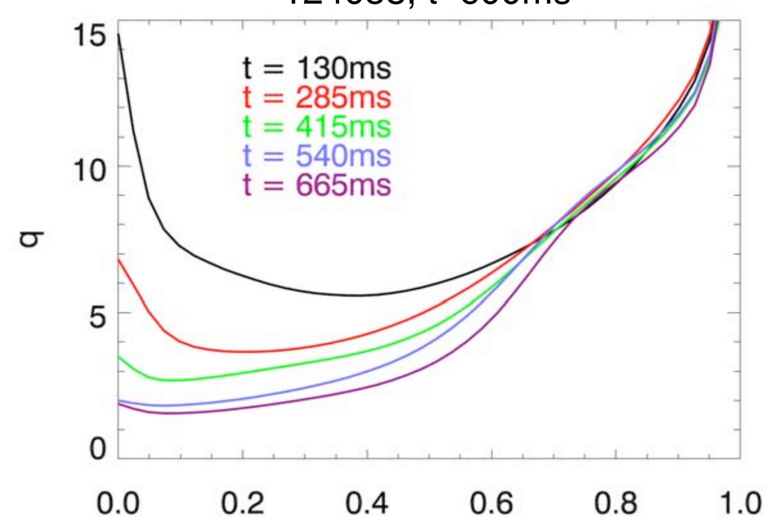
124058, 600ms (LRDFIT06)

κ= 2.65, δ_{X-L} = 0.8
δR_{SEP} = -1.0cm



- In 2006 achieved world record plasma elongation
  - κ = 3
- In 2007 maintained κ = 2.7
- Combined with high-q startup giving very low l_i~0.4

MSE reconstructed q-profile
124058, t=600ms



- *PAC-21 - 41*

NSTX contributes to ITPA activities on a broad front

Actively involved in 18 joint experiments – contribute/participate in 25 total

Boundary Physics

- 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

Macroscopic stability

- MDC-2 Joint experiments on resistive wall mode physics
- MDC-3 Joint experiments on neoclassical tearing modes including error field effects
- MDC-12 Non-resonant magnetic braking
- MDC-13: NTM stability at low rotation

Transport and Turbulence

- CDB-2 Confinement scaling in ELMy H-modes: b degradation
- CDB-6 Improving the condition of global ELMy H-mode and pedestal databases: Low A
- CDB-9 Density profiles at low collisionality
- TP-6.3 NBI-driven momentum transport study
- TP-8.1 NSTX/MAST ITB similarity experiments
- TP-9 H-mode aspect ratio comparison

Wave Particle Interactions

- MDC-11 Fast ion losses and redistribution from localized Alfvén Eigenmodes

Advanced Scenarios and Control

- SSO-2.2 MHD in hybrid scenarios and effects on q-profile
- MDC-14: Vertical Stability Physics and Performance Limits in Tokamaks with Highly Elongated Plasmas

NSTX has met all program milestones, made world leading contributions towards advancing the ST concept to NHTX and an ST-CTF, and contributed to several ITPA topics

- Effectively incorporated mode feedback and error field correction
  - Maintains edge plasma rotation
- Documented a wide range of fast particle MHD behavior
  - Relevant to ITER and to future ST devices
- Measured electron gyro-scale turbulence in a variety of conditions,
  - Helping to shed light on the long standing mystery of electron transport
- Improved LITER deposition
  - Enables study of low recycling boundaries with improved confinement
- Reduced power to the divertor in long pulse high performance H-mode plasmas with strong shaping
  - Crucial to future ST devices and fusion reactors in general

Summary, continued

- Coupled CHI plasmas to Ohmic
  - Incorporating Solenoid free start-up into normal operations
- Lithium reduces collisionality plasma in boundary, increasing EBW transmission efficiency
  - Clarifies utility of EBW as a heating tool for overdense plasmas
- Understood HHFW coupling to surface waves, explaining the improved heating efficiency at higher toroidal field
  - RF coupling physics is generic to all toroidal devices
- Maintained high elongation κ ~ 2.7 plasmas in steady state
  - Demonstrates high fbs scenarios for future ST devices

- *NSTX continues to contribute to fundamental toroidal confinement in support of future STs and ITER*