

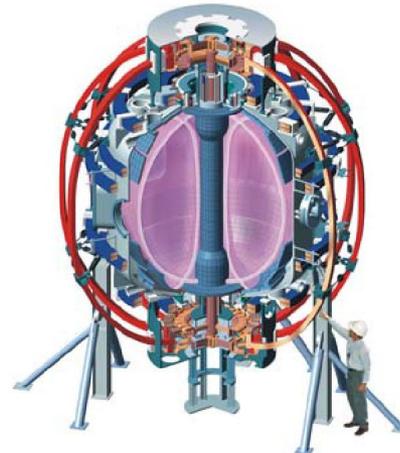
Supported by



Energetic Particle Physics Research On NSTX

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for the NSTX research team

*21st NSTX PAC Meeting
PPPL, January 18th, 2007*



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Research objectives and major milestones

Objectives of NSTX experiments are studies of:

- 1. instabilities driven by energetic particles (EP=beam ions) in presence of high beam and plasma β , low- R/a , high- V_{EP}/V_A (unique parameter space):*
 - thresholds for EP driven instabilities (ITPA, task mdc10: TAE damping rates)*
 - effect of multiple modes on the transport of fast ions (mdc11: EP transport)*
 - saturation and dynamic behaviour of mode amplitude (mdc11)*
 - dependence of fast ion transport on mode amplitude (mdc11)*
- 2. effects of these instabilities on (a) EP confinement; (b) plasma performance: current drive, plasma heating, transport etc.*
- 3. advanced diagnostics: NPA, FIDA, CAE/ICE (ITER issue card)*

MILESTONES:

- 2007 Joule milestone: Measure, identify and characterize modes driven by super-Alfvénic ions*
- 2009 milestone: Study how $j(r)$ is modified by super-Alfvénic ion driven modes.*

Present and future plans build upon new discoveries in unique ST conditions

□ Past research, linear physics, EP confinement, single mode effects:

- new, high frequency ($\sim\omega_{ci}$) modes, CAEs/GAEs
E. Fredrickson, et.al. Phys. Rev. Letter, v.87, p.145001-1 (2001)
- new types of fishbones, bounce-frequency,
E. Fredrickson et.al. Nucl. Fusion, v.43, p.1258 (2003).
- tentative identification of BAEs: new, beta Alfvén/acoustic eigenmodes in high β plasma,
Gorelenkov, Bulletin APS, v.51, p.183 (2006) paper NO1 10.
- Alfvén cascades observation in NSTX in '06 at the same time as MAST,
Fredrickson, submitted to PRL.

□ Present research, multi-mode EP transport:

- Initial studies of multiple mode driven EP transport
Fredrickson, Nucl.Fusion v.46, p.S926 (2006)
Medley, 21 Fusion Energy Conference, IAEA, Chengdu, 2006.
- Three wave coupling effect in the presence of strong EP drive,
N. Crocker, Phys. Rev. Letter, v.97, p.045002-1 (2006).

□ Future research, AE effects on current drive, phase space engineering:

- Interchange-type mode induced current redistribution via EP redistribution,
J. Menard, et.al. Phys. Rev. Letter, v.97, p.095002-1 (2006).
- may cause stochastic heating of thermal ions (energy channeling)
Gates, Phys. Rev. Letter, v.87, p.205003-1 (2001)



New Hardware Tools

FY07 (essential diagnostics are highlighted)

- ❑ Additional reflectometers (3 => 6 channels)
 - ❑ max density increased from 3.1 to 5.3 x 10¹³)
- ❑ Fast profile reflectometer (<50 kHz)
 - ❑ High resolution eigenmode structures for lower frequency modes
- ❑ Fast NPA, vertical scan, ssNPA
- ❑ Soft x-ray cameras (with impurity doping to improve sensitivity)
- ❑ Additional Firetip channels (<250 kHz), mode amplitude and structure
- ❑ n=3 non-resonant plasma braking, eliminate complexity of sheared rotation
- ❑ Faraday cups to measure fast ion losses

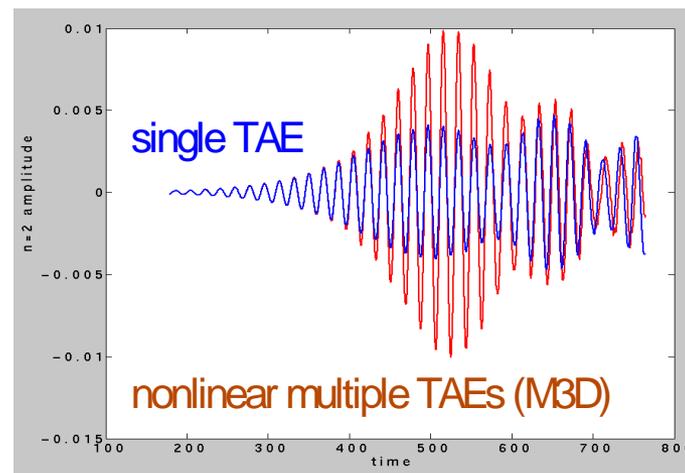
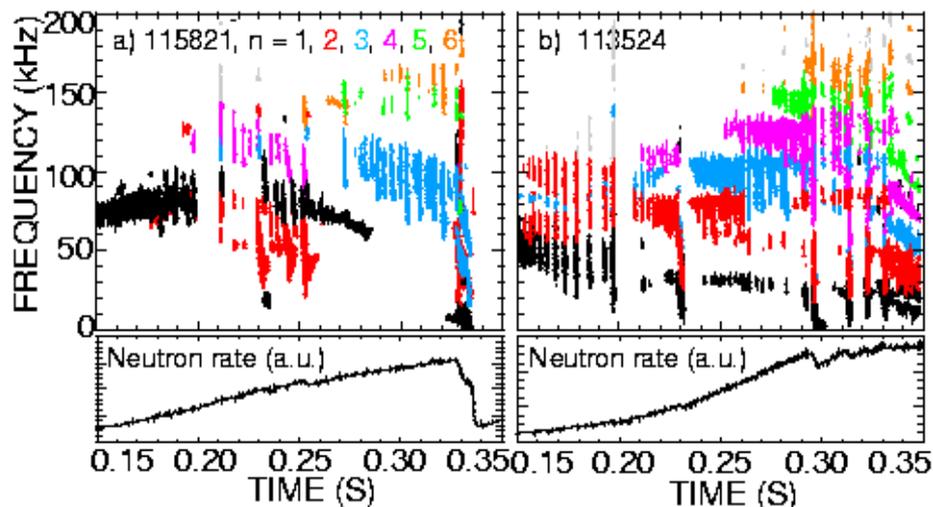
FY08 and FY09

- ❑ FIDA (Fast Ion D-Alpha, '08).
- ❑ Faster profile reflectometer
- ❑ Faster Firetip (\approx 2-3 MHz bandwidth)



Main objective at present: EP transport induced by multiple modes

- Phase-space islands overlap with multiple modes should lead to large EP redistribution.
- Overlap triggers "avalanche" where multiple modes are destabilized.
- Relevant to small ρ^* regime

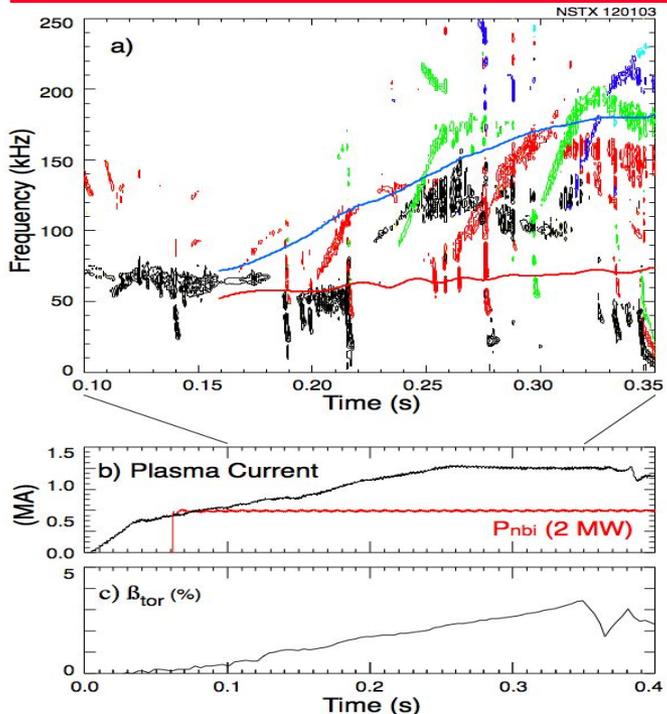


Experiments will provide (1st priority for '07):

- Modes structure and amplitude.
- Excitation thresholds via power-scaling.
- Three wave coupling effects on fast ion confinement.
- EP profile measurements to verify predictive capabilities of codes like M3D and theory.



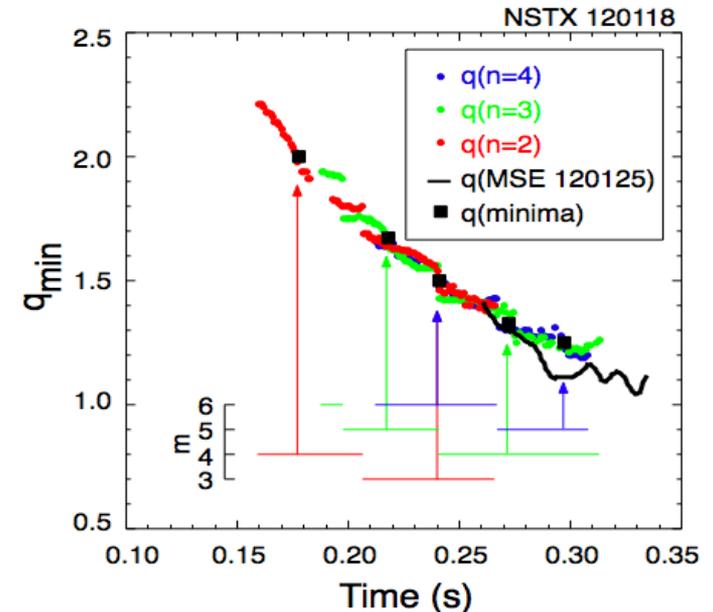
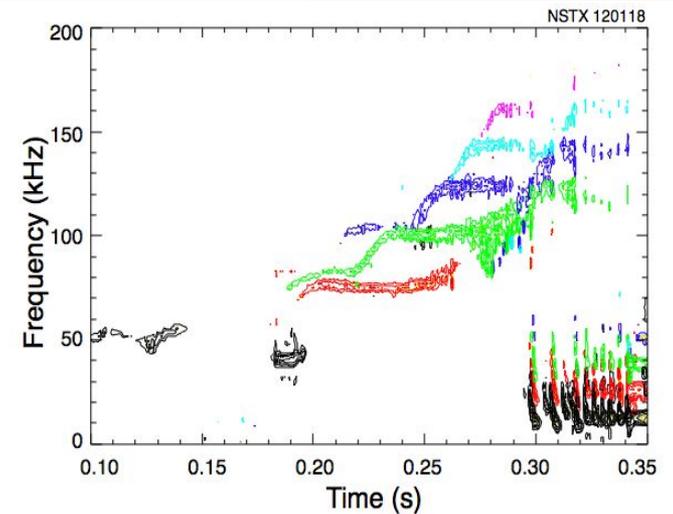
Alfvén Cascades (RSAE) observed at low β_e and verified on NSTX (also on MAST)



RSAE should exist for $\beta q_{\min}^2 \ll 1/4\gamma$.
(merged into TAE gap)
(IFS-PPPL collaboration)

PAC19 question

Frequency chirp reveals evolution of q_{\min} .

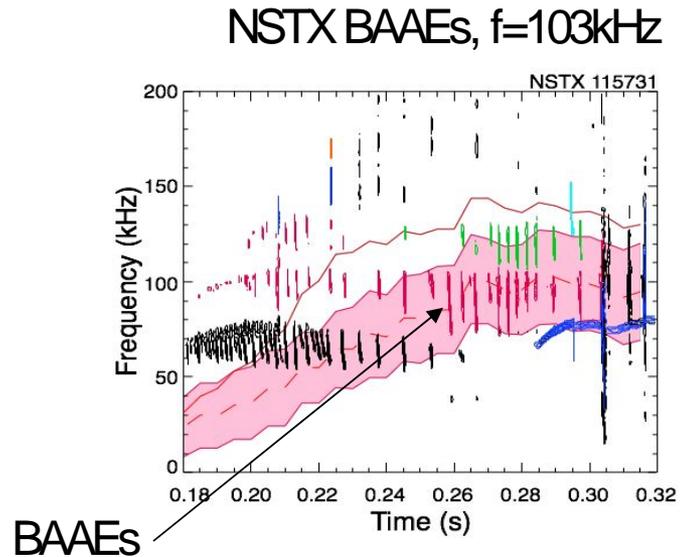


Experiments will provide (1st priority for '07):

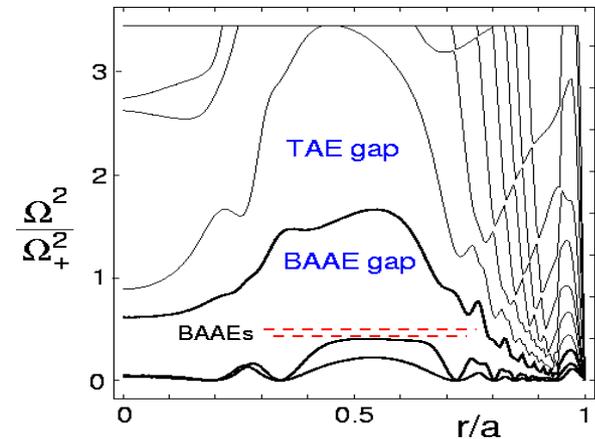
- ❑ Mode structure localization to q_{\min} by reflectometers.
- ❑ Evolution of mode structure at transition to TAE.
- ❑ Use RSAEs frequency for q reconstruction and verify MSE-constraints.
- ❑ Study effect of rotational shear by applying "non-resonant $n=3$ braking".
- ❑ Verify GAM/BAE coupling for Alfvén/acoustic.

Tentative identification of β -induced Alfvén-Acoustic Eigenmodes (BAAE) in unique ST conditions at high beam and plasma β

- EP driven modes are often seen at frequencies much lower than expected for TAE.
- Couples two fundamental MHD branches - new.
- Joint studies with JET (low density, high EP pressure plasmas).



NOVA on BAAE gap in NSTX



IFS-PPPL collaboration

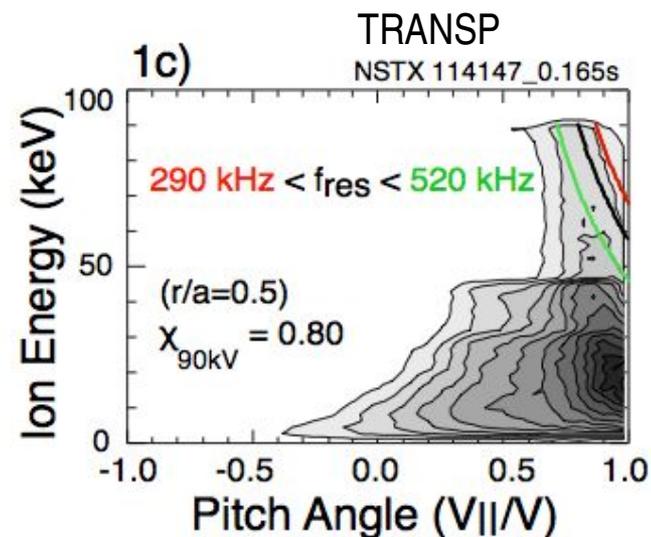
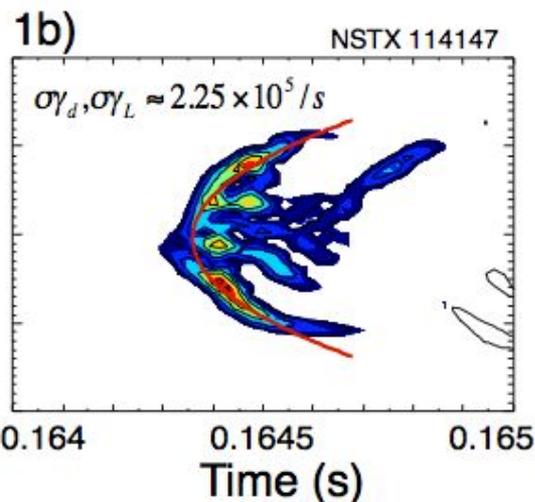
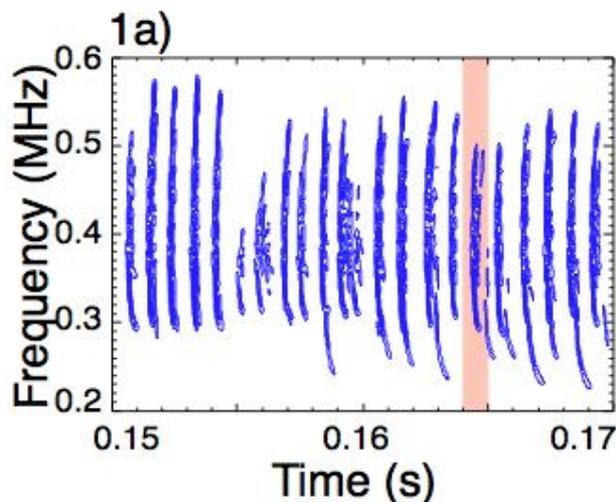
Experiments will provide (2nd priority for '07):

- BAAE radial structure: is it localized to q_{\min} ?
- Unfold effects of plasma rotation by applying $n=3$ braking.
- Measure fast ion redistribution to assess effects on their confinement.



Phase space engineering via HHFW: preliminary observations of Angelfish stabilization as predicted by theory

- ❑ Angelfish are identified as a form of hole-clumps in the phase space.
- ❑ Mode satisfies Doppler-shifted resonance condition for TRANSP calculated fast ion distribution.
- ❑ Growth rate estimates from slowing down distribution for the CAE is 0.04; from the frequency sweep 0.053.
- ❑ Engineering of fast-ion phase space can suppress deleterious instabilities.
- ❑ Potentially important tool for EP instability studies.



Experiments may provide (part of 2nd priority '07 and future plans)

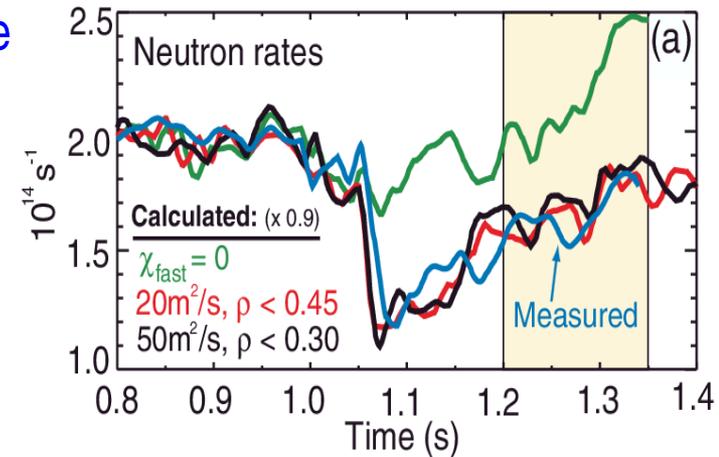
- ❑ Mode amplitude and structure to identify CAE vs. GAE.
- ❑ RF power thresholds, *i.e.*, effective fast ion diffusivity, v_{eff} , to suppress chirps to validate theory, which predicts > 2 MW is sufficient to affect hole-clump frequency chirps.

IFS-PPPL collaboration
H.Berk, 21st FEC, Chengdu, 2006



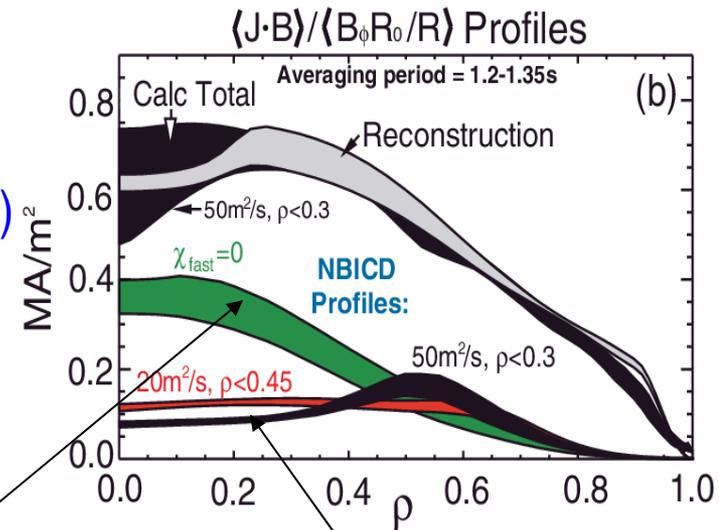
*AE effect on NBI current drive is in focus of future research: modeling technique is being developed

- ❑ Interchange mode has been identified to be responsible for NBI current drive profile broadening.
- ❑ Neutron rate, MSE q-profile constrain theory and TRANSP modeling of NBI current drive.
- ❑ Significant current redistribution is inferred.
- ❑ The same technique will be used for EP driven mode effects on NBI current drive.



Experiments will provide (initial study '07,'08, '09 milestone)

- ❑ Benchmark current drive models used in TRANSP
- ❑ NPA measurements of energy spectrum/pitch angle of redistributed ions.
- ❑ Extension to other instabilities.



J. Menard, et.al. Phys. Rev. Letter, v.97, p.095002-1 (2006).

classical $j(r)$

model $j(r)$ consistent with measured neutron rate

Strong theory support needing benchmarks in unique ST parameter space

Supported theoretical tools under development

- ❑ Nova-Orbit – linear-quasilinear, hybrid MHD/kinetic
 - ❑ Fast ion losses during Avalanches, EPMs (resonance overlap)
 - ❑ Long standing conundrum (TFTR, DIII-D, etc.) on EP loss with measured mode amplitudes to be addressed due to large FLR effect in ST
- ❑ NOVA-KN – linear, hybrid MHD/kinetic, nonperturbative code
 - ❑ Efficient calculations of linear physics of EPM like mode: ideal for strong driven modes like in NSTX (exploit high beam beta)
- ❑ M3D-k – fully nonlinear, hybrid kinetic
 - ❑ EPM/TAE/BAAE nonlinear selfconsistent for *multimode* (resonant overlap) simulations
- ❑ HYM – fully nonlinear, hybrid kinetic
 - ❑ Non-linear GAE/CAE simulations
 - ❑ Chirping frequency modes, Angelfish.
- ❑ HINST – linear ballooning, fully kinetic
 - ❑ KBM like modes with strong EP drive for potential applications in NCSX
 - ❑ BAAE kinetic nonperturbative (high beta) treatment to address Alfvén/acoustic coupling

'07 PPPL lead theory Joule milestone is to use predictive capabilities of TRANSP and NOVA-K codes for ITER TAE stability study.



2007 Experiments Address Near Term Research Objectives

❑ MHD Prioritized Experiments (from NSTX Forum – Dec 2006)

ST devel.
ITER
physics

	ST devel.	ITER	physics	
3 days	❑ Multi-mode beam loss power scan	X	X	X
	● Generation of *AE quiescent plasmas	X		
	● Beam power scan of fast ion loss induced by multiple MHD modes	X	X	X

4.5 days	❑ Alfvén cascades on NSTX	X	X	X
	❑ Beta-induced Alfvén-acoustic modes	X	X	X
	● Three-wave coupling effects on fast-ion loss		X	X
	● Stabilization of CAE/GAE hole-clumps			X

	❑ MHD-induced energetic particle redistribution - vsNPA	X	X	X
	❑ RF beat wave excitation of *AE		X	X
	❑ Structure of Bounce-Resonance Fishbone-like Modes with $n > 1$			X
	❑ ρ beam ion scan for NBI driven modes (NSTX & DIII-D)	X	X	X
	❑ TAE hole-clumps		X	X
	❑ CAE/GAE stochastic thermal ion heating	X	X	X
	❑ Ion power balance with modulated NBI	X		X

(Red highlight = addresses NSTX milestone)

2007 High Priority Experiments address Joule milestone and PAC recommendations

- EP redistribution induced by multiple MHD modes MDC11,ITER relevant, PAC19 question
 - Fast ion β (beam power) scan to measure mode onset threshold
 - Documentation of multi-mode fast-ion transport regime
 - High spatial resolution eigenmode structure/amplitude measurements - determine "island overlap" condition
 - NPA scan to measure energy spectrum of redistributed fast ions
- Part II: Generation of *AE quiescent plasmas PAC-19 question
 - Data to benchmark TRANSP beam/bootstrap current calculations
 - Vertical NPA scan to document fast ion redistribution after mode onset.
- Alfvén cascades on NSTX - PAC-19 question
 - Verify that frequency sweeping modes are Alfvén Cascades with MSE q
 - High spatial resolution reflectometer data to show localization to q_{\min} .
 - Show transition from GAM to TAE at frequency saturation
 - Document proposed β dependence of frequency sweep range
 - Study physics of GAMs or BAEs



2007 Lower Priority experiments (results expected in piggy-back)

- ❑ Beta-induced Alfvén-acoustic modes
 - ❑ Some data potentially available from L-mode confinement experiments
- ❑ Three-wave coupling effects on fast-ion loss
 - ❑ Some data available from other L-mode experiments
- ❑ MHD-induced energetic particle redistribution - vsNPA
 - ❑ Intrinsic to Multi-mode beam loss XP
- ❑ HHFW stabilization of CAE/GAE hole-clumps
 - ❑ Planned as non-intrusive part of fast ion XPs - assuming Angelfish are present.
- ❑ RF beat wave excitation of *AE
 - ❑ Partly incorporated into other XPs as proof-of-principle and possibly as measure of mode linear damping rate
- ❑ ρ_L ion scan for NBI driven modes (NSTX & DIII-D)
 - ❑ Some data expected from TF scan planned for Alfvén Cascade experiment
- ❑ CAE/GAE stochastic thermal ion heating
 - ❑ Preliminary measurements of HHFW antenna coupling to beam driven CAE/GAE hoped for in last week of campaign
 - ❑ Possibly some preliminary antenna loading measurements.