

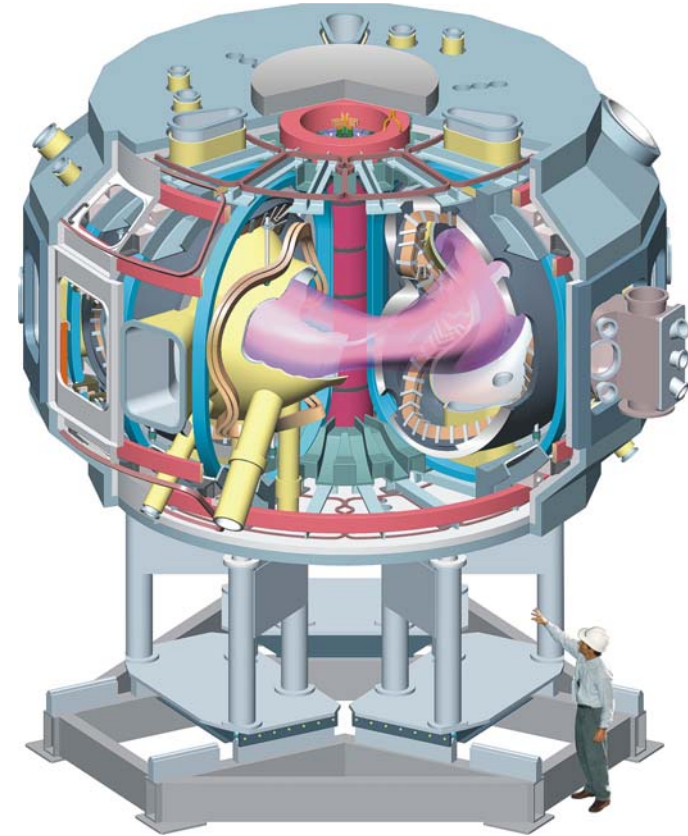
NCSX Research Planning

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For the NCSX Team

PAC Conference Call
19 July 2007

Developments Since PAC Meeting

- First NCSX Research Forum, 7 Dec. 2006
 - 12 Collaborator contributions
- Re-planning of MIE Construction Project
 - CD-4 milestone delayed until Dec. 2011
- ARIES-CS study completed
 - COE lower than ARIES-RS
 - Report in refereeing
- ECH Collaboration with IPP
 - 70GHz system shipped



Need to re-plan the research program for new schedule.

ARIES-CS: a Competitive, Attractive Reactor

Reference parameters
for baseline:

$$\langle R \rangle = 7.75 \text{ m}$$

$$\langle a \rangle = 1.72 \text{ m}$$

$$\langle n \rangle = 4.0 \times 10^{20} \text{ m}^{-3}$$

$$\langle T \rangle = 6.6 \text{ keV}$$

$$\langle B \rangle_{\text{axis}} = 5.7 \text{ T}$$

$$\langle \beta \rangle = 6.4\%$$

$$H(\text{ISS95}) = 2.0$$

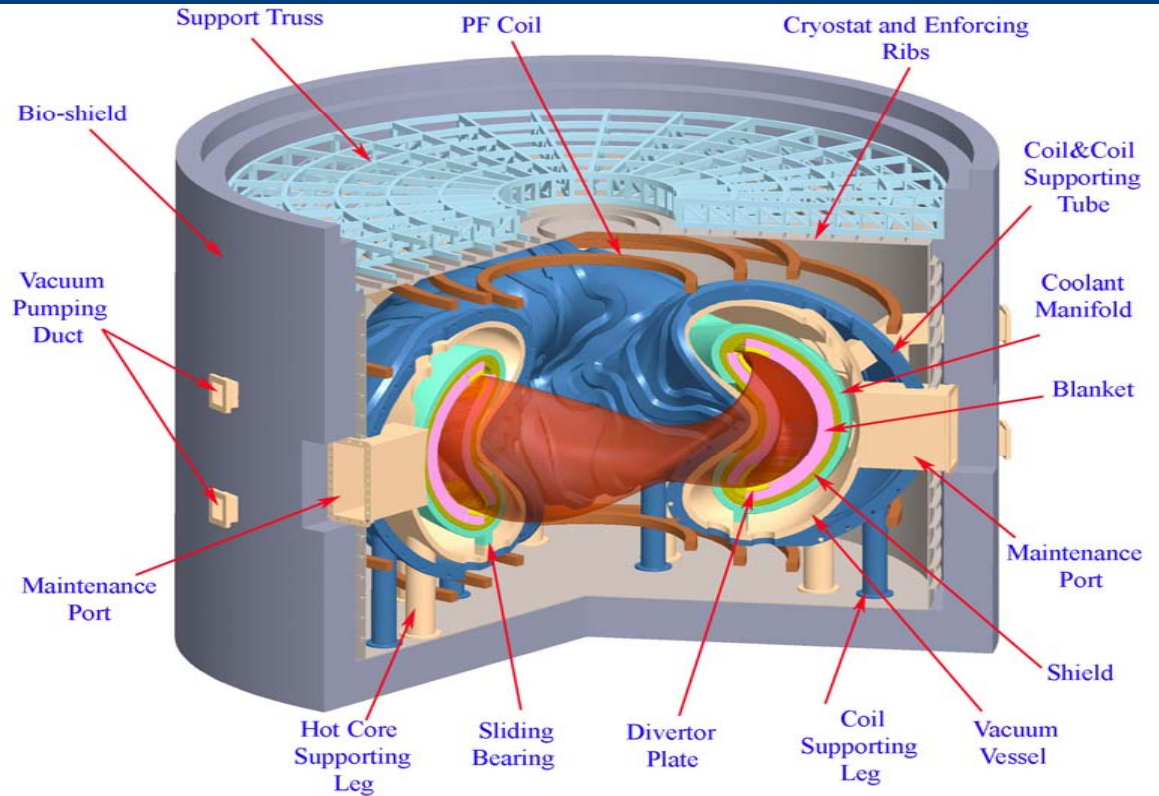
$$H(\text{ISS04}) = 1.1$$

$$I_{\text{plasma}} = 3.5 \text{ MA}$$

(bootstrap)

$$P(\text{fusion}) = 2.364 \text{ GW}$$

$$P(\text{electric}) = 1 \text{ GW}$$



Aries-	-I	-RS	-CS	-AT	-CS
Blanket			LiPb/FS	LiPb/SiC	LiPb/SiC
COE(92)	99.7	75.8	61.3	47.5	48.

Based on NCSX design

70 GHz ECH Equipment Shipped



- Collaborative agreement with IPP
- 0.6MW 70GHz 2sec systems donated to NCSX
- Gyrotrons and some other components are at JFK airport
 - Going through Customs

NCSX Research Mission

Remains the Same

Acquire the physics data needed to assess the attractiveness of compact stellarators; advance understanding of 3D fusion science.

Understand...

- Pressure limits and limiting mechanisms in a low-A optimized stellarator
- Effect of 3D magnetic fields on disruptions
- Reduction of and anomalous neoclassical transport by quasi-axisymmetric design.
- Confinement scaling; reduction of turbulent transport by flow shear control.
- Equilibrium islands and tearing-mode stabilization by design of magnetic shear.
- Compatibility between power and particle exhaust methods and good core performance in a compact stellarator.
- Energetic-ion stability and confinement in compact stellarators

Demonstrate...

- Conditions for high β , disruption-free operation
- High pressure, good confinement, compatible with steady state

Develop the physics understanding and basis for the Aries-CS plasma.

Initial Heating Experiments: Scientific Goals

What high priority results and papers should be produced?

Prioritized

- (1) A. Effect of quasi-axisymmetry on plasma global confinement
- (1) B. Comparison of very low ripple stellarator global confinement with scalings
- (1) C. Effect of 3D equilibrium on SOL characteristics and contact footprint

- (2) D. Effect of quasi-axisymmetry on rotation damping
- (2) E. Does pressure-driven linear MHD stability is limiting (e.g. disruptions)

- (3) F. Equilibrium reconstruction in NCSX
- (3) G. Comparison of measured and calculated linear MHD stability
- (3) H. Whether current-driven linear MHD stability is limiting w/ reversed shear (e.g. disruptions)
- (3) I. Occurrence of pressure driven islands vs iota and shear

As discussed at PAC meeting, Research Forum.

NCSX Experimental Campaigns

FY-08	FY-09	FY-10	FY-11	FY-12	FY-13	FY-14	FY-15
Fabrication Project Phase 1 & 2 Equipment				1	2	3	4
			1st Plasma	△			
			Phase 2 Equipment				
						Full field, more diags.	
						Full PFCs & divertor	

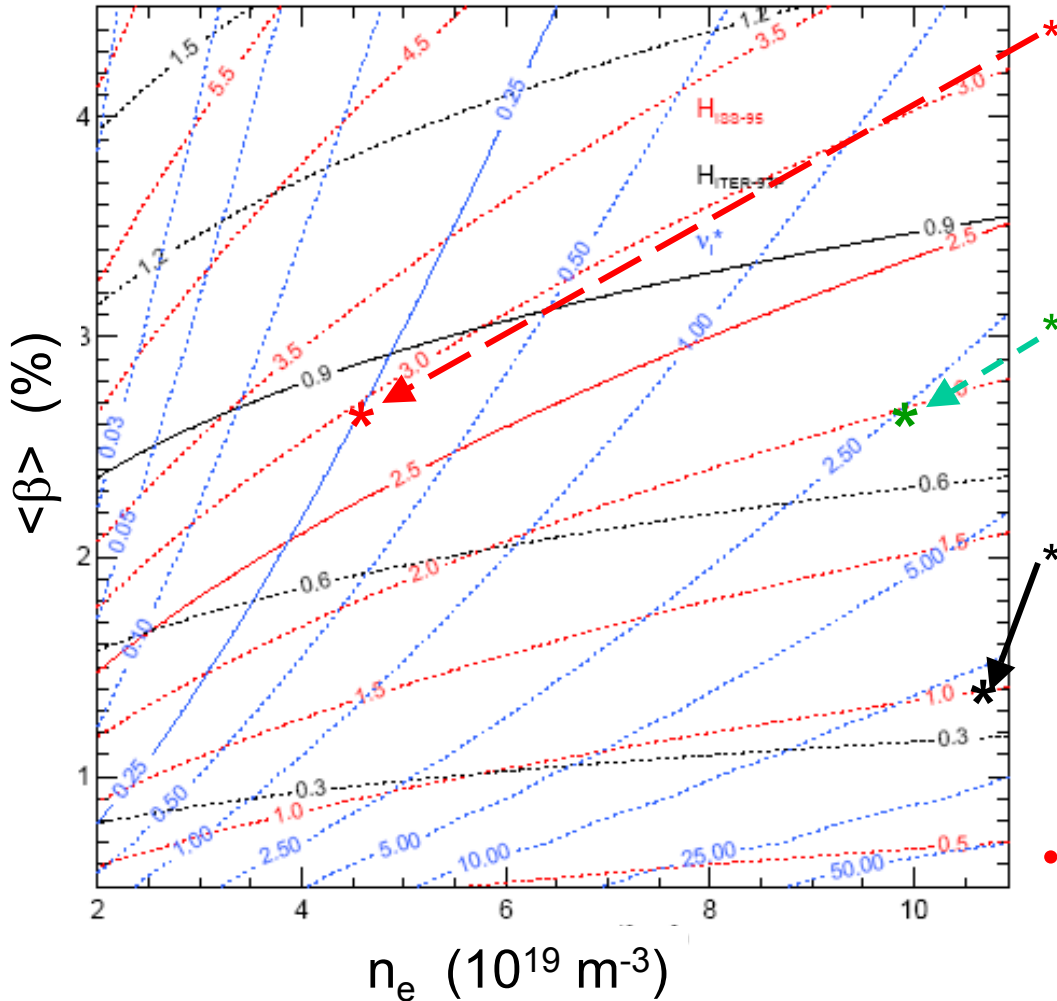
Research Phases **delayed by ~2 years**, compared to previous plan:

1. Stellarator Acceptance Testing & First Plasma (Fabrication Proj.)
2. Magnetic configuration studies
 - electron-beam mapping studies
3. Initial Heating Experiment
 - 3MW NBI. ECH.
 - $B \geq 1.2T$
 - Partial PFC coverage
 - Initial diagnostics, magnetics, profiles (n_e , T_e , T_i , v_ϕ , P_{rad}) & SOL
4. High beta Experiments
 - 6MW heating
 - $B = 2T$; divertor
 - Improved diagnostics

Wide Range of β and v^* Accessible in FY13

Contours of H_{ISS95} , $H_{ITER-97P}$, and $\min v_{*i}$

$B = 1.2$ T, 3MW NBI



$\beta=2.7\%$, $v_{*i}=0.25$ with
 $H_{ISS95}=2.9$; $H_{ISS04}=1.5$
 $H_{ITER-97P}=0.8$

$\beta=2.7\%$, $v_{*i}=2.5$ with
 $H_{ISS95}=2.0$; $H_{ISS04}=1.0$

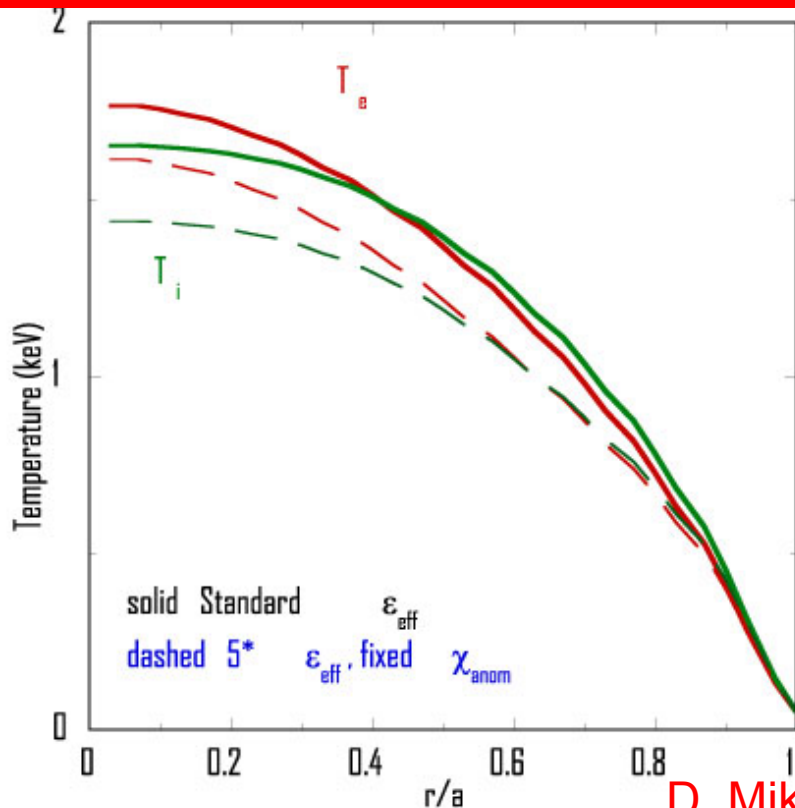
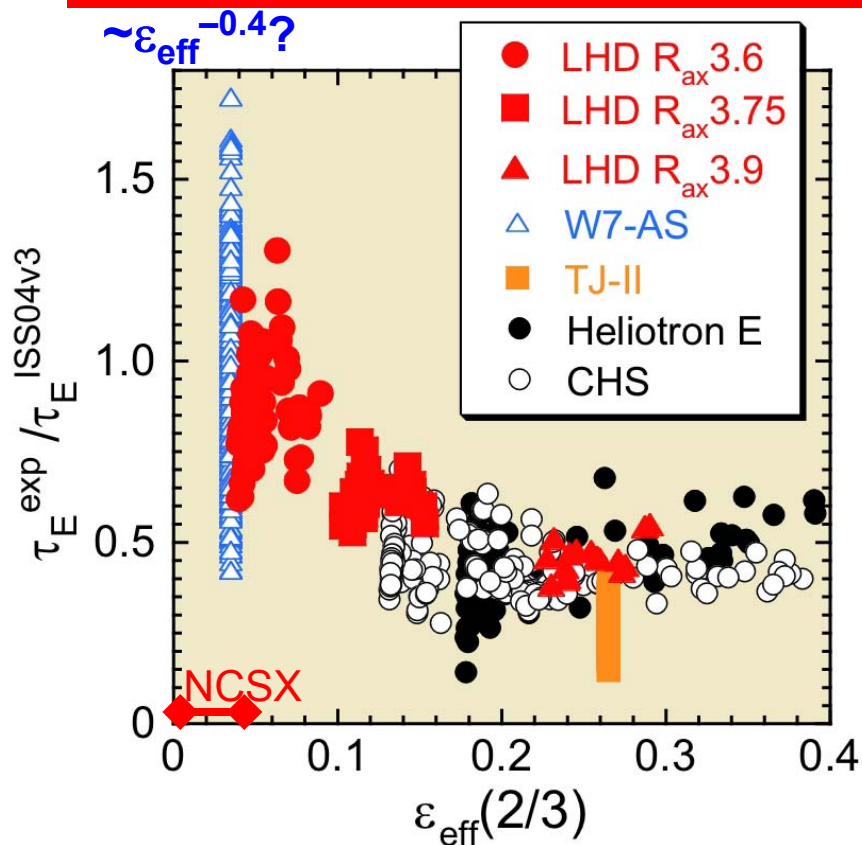
$\beta=1.4\%$, collisional with
 $H_{ISS95}=1.0$, ; $H_{ISS04}=0.5$
 sufficient to test stability theory

- If get $H_{ITER-97P} \sim 1.2$, can access $\beta=4\%$ with 3MW

LHD and W7-AS have achieved $H_{ISS95} \sim 2.5$

PBX-M obtained $\beta = 6.8\%$ with $H_{ITER-97P} = 1.7$ and $H_{ISS95} \sim 3.9$

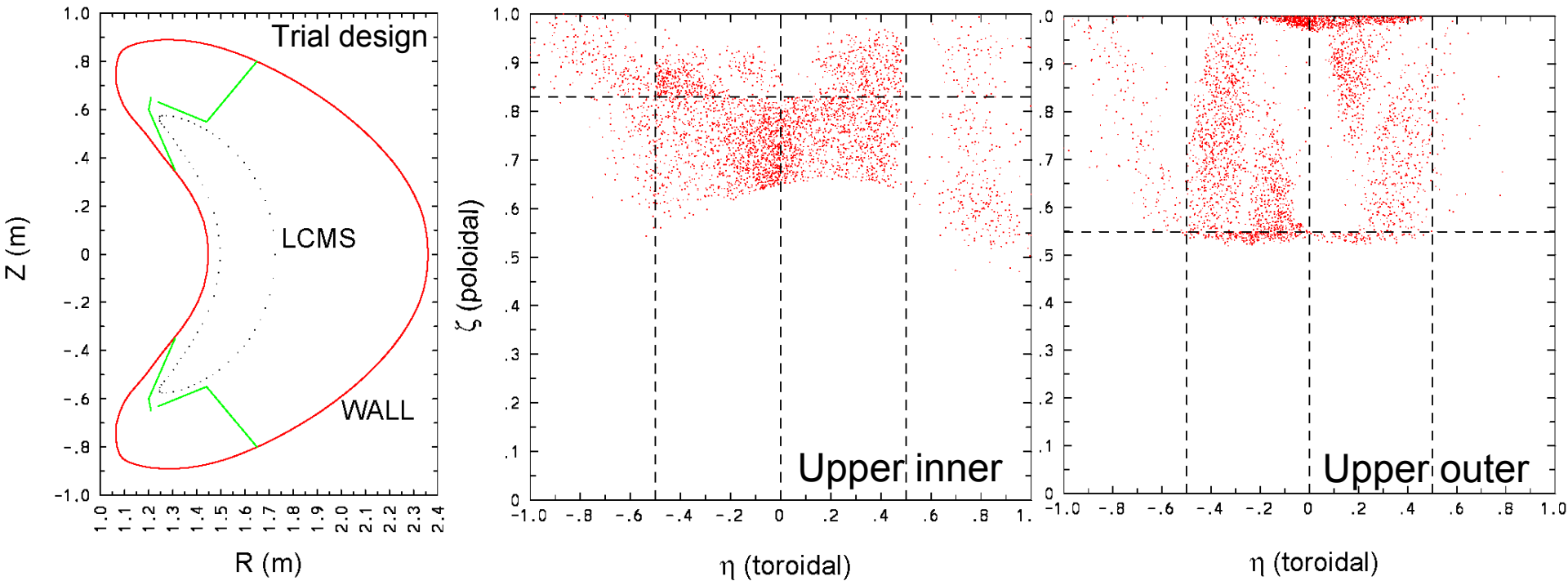
(1) A. Effect of quasi-axisymmetry on global confinement
 (1) B. Comparison of very low ripple confinement with scalings



D. Mikkelsen
 N. Pomphrey

- **NCSX can vary the effective ripple by more than a factor of 10**
 - From far below any other experiment, to overlapping existing range
- **Transport simulations: profiles and confinement should be sensitive to ripple over this range**
- **At lowest ripple, ripple-driven transport is negligible**
- **Does anomalous transport depend on ripple? 3D Shaping?**

(1) C. Effect of 3D equilibrium on SOL characteristics and contact footprint



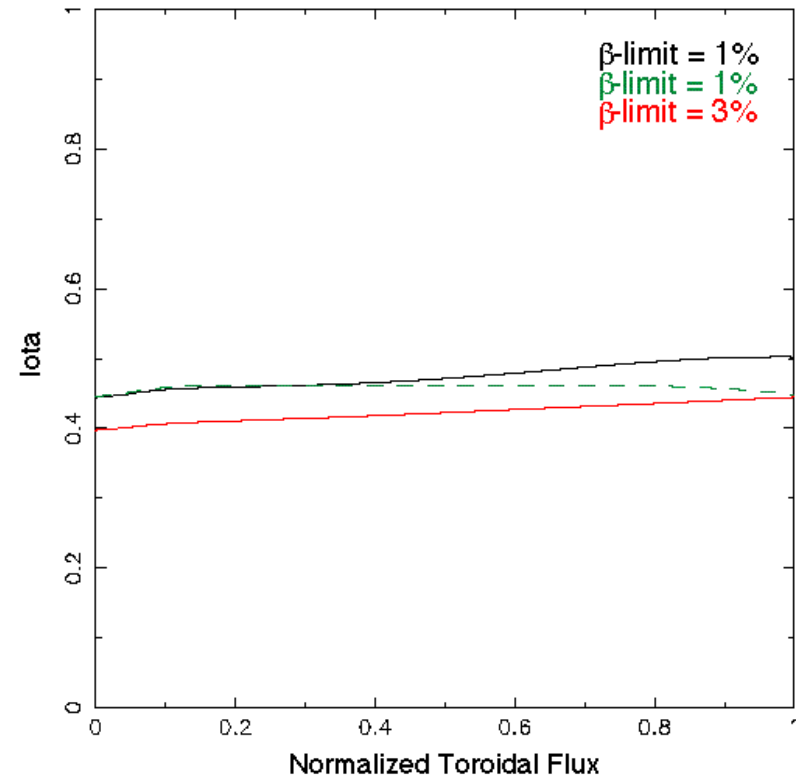
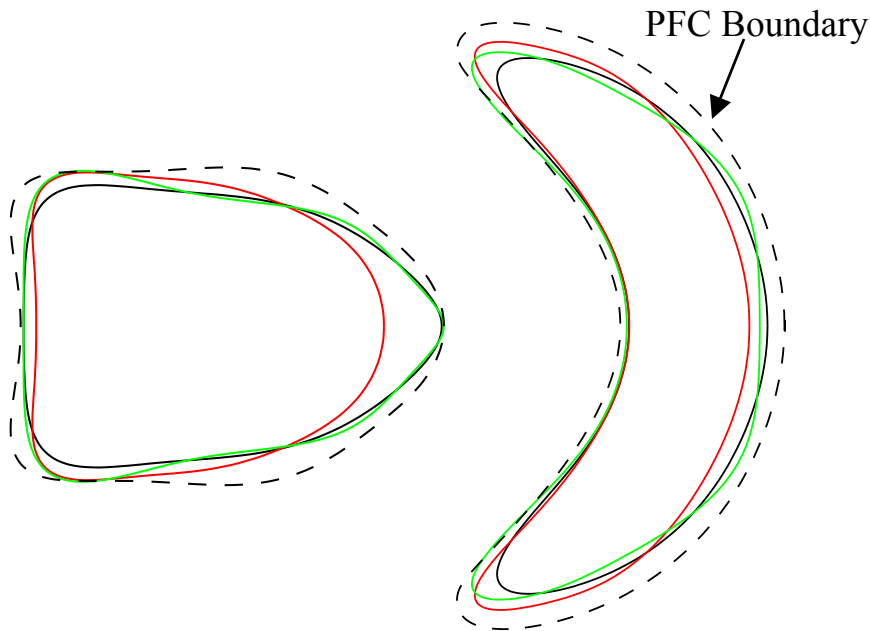
T. Kaiser

- Preliminary calculations: field line following outside LCMS with perpendicular diffusion ($D = 1 \text{ m}^2/\text{sec}$).
- Clear structures in contact that can be diagnosed with planned probes or by planned cameras.
- Further design work on divertor and PFC structure planned.

(2) E. Is pressure-driven linear MHD stability limiting (e.g. disruptions)

(3) G. Comparison of measured and calculated linear MHD stability

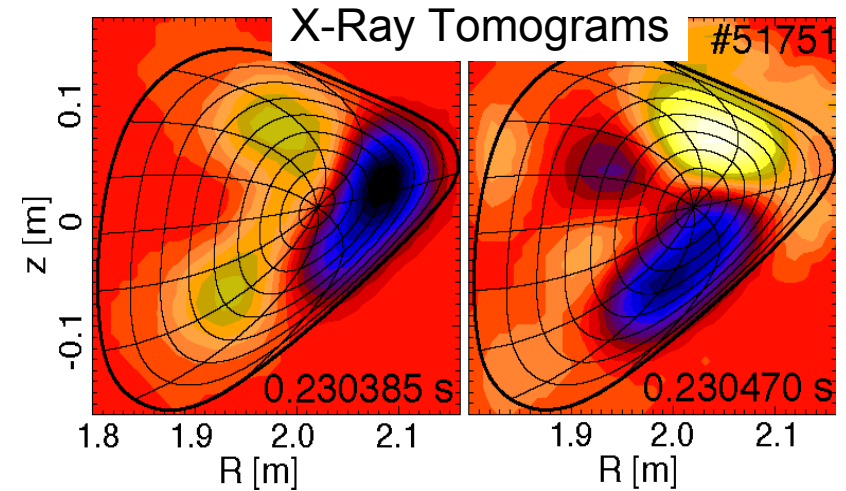
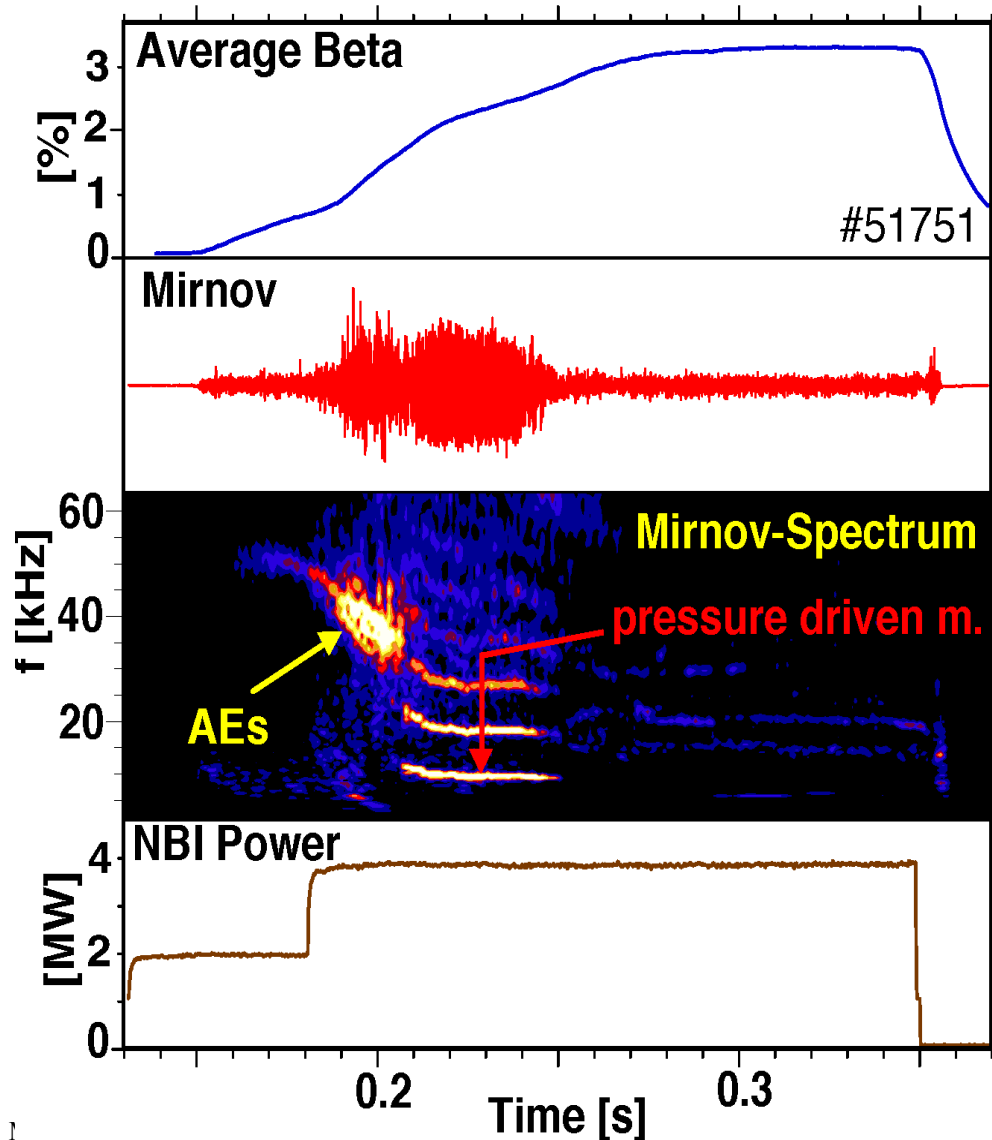
- Marginally stable β for ideal external kink changed from 3% to 1% by modifying plasma shape
 - either with fixed shear or fixed edge-iota !
- Can increase kink marginally stable β to $> 6\%$ by adjusting iota and shear.



(2) E. Is pressure-driven linear MHD stability limiting (e.g. disruptions)

(3) G. Comparison of measured and calculated linear MHD stability

Is situation similar to W7-AS & LHD?: external kink instabilities were not limiting



- Dominant mode $m/n = 2/1$.
- Reasonable agreement CAS3D and Terpsichore linear stability calcs. Predicted **2/1 external kink** threshold $\beta < 1\%$
- Does not inhibit access to higher β **Linear stability threshold is not indicative of β limit.**

Initial Heating Experiments

Programmatic Goals

Prioritized

- (1) Demonstrate basic real-time plasma control (I_p , n_e)
- (1) Characterize confinement and stability
 - Variation with global parameters, e.g. ι , shear, I_p , density, rotation...
 - Sensitivity to low-order resonances
 - Operating limits
- (1) Characterize SOL properties for different 3D geometries, prepare for the first divertor design.

- (2) Investigate momentum transport and effects of quasi-symmetry
- (2) Test MHD stability at moderate β , dependence on 3D shape

- (3) Explore ability to generate transport barriers and enhanced confinement regimes.
- (3) Investigate local ion, electron transport and effects of quasi-symmetry

As discussed at PAC meeting, Research Forum.

FY10-12: NCSX Diagnostic Upgrades for FY13

Initial diagnostic upgrades

- In-vessel magnetic diagnostics + instrument external magnetics diags.
 - Thomson-scattering profile (10 core, ~5 edge channels, multipulse)
 - Imaging x-ray crystal spectrometer (v_ϕ , T_i)
 - UV spectrometer
 - PFC-mounted probes
 - Filtered 1D and 2D cameras. Filterscopes.
 - IR cameras
 - SXR camera
 - Bolometer array
-
- DNB and toroidal CHERS profile (v_ϕ , T_i , n_C)
 - MSE
 - SXR tomography

Black: shared w/ NSTX
may be more

Phase 4 Diagnostics

Collaborations on diagnostics are expected, choices still being discussed.

FY10-12: Equipment Upgrades for FY13

Major elements:

- Data acquisition and control systems
 - acquisition of diagnostics, data infrastructure
 - diagnostic control; initial plasma feedback control

Plan: PC-based acquisition; MDS+ organized similar to NSTX
- Heating systems
 - 3MW NBI refurbishment and installation (co- & ctr-)
 - 0.6MW 70GHz ECH heating, via collaboration with MP/IPP
- Plasma facing components and NB armor
 - partial liner inside vacuum vessel (~1/3 coverage)
 - wall conditioning & boronization
- Power systems (supporting 1.2T operation)
 - Modular coils and TF powered from D-site, PF coils from C-site
 - Merged C/D-site interlocks and controls
 - Power for diagnostics

Black: shared w/ NSTX

Next Steps

- Lehman Review, 15-17 August
 - Charge requests review of Research Upgrade cost and schedule plans
- OFES: ‘Focused science/programmatic review of Compact Stellarator Program after the Lehman review’
- Funding for Research Upgrades and team building now expected to start in FY10.
 - Expect next Research Forum in FY09.

