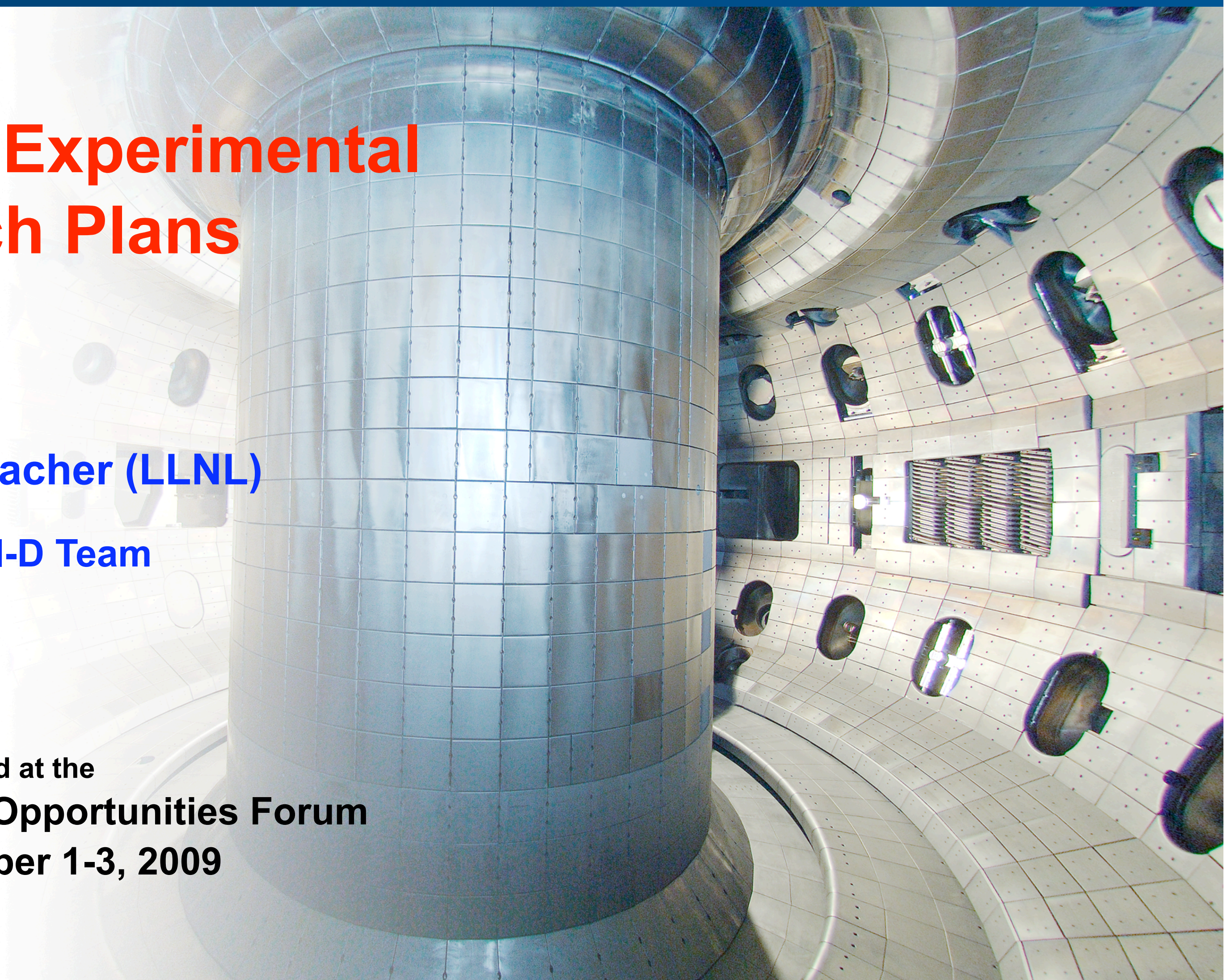
2009-10 DIII-D Experimental Research Plans

M.E. Fenstermacher (LLNL)

For the DIII-D Team



Presented at the

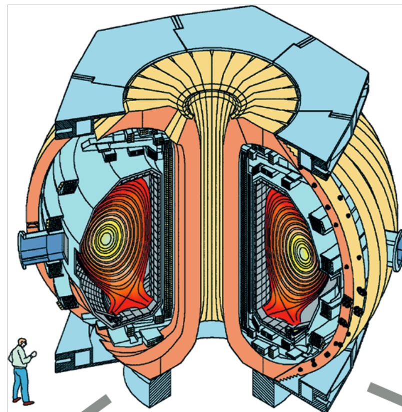
2010 NSTX Research Opportunities Forum

PPPL, December 1-3, 2009

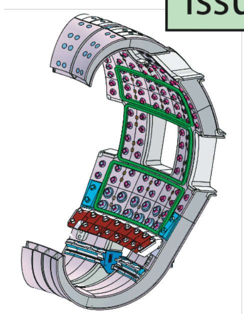
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and under Contracts DE-FC02-04ER54698, DE-FG02-07ER54917, DE-FG02-05ER54809.

DIII-D Research Contributes to Solutions of ITER Issues, Advanced Scenario Development and Basic Fusion Science

DIII-D

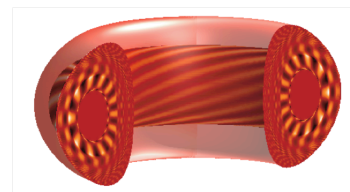


ITER Baseline Issues



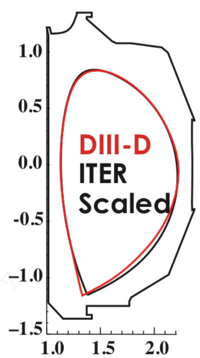
- ELM Control
- Rapid Shutdown
- Tritium Inventory
- Pedestal Width
- He or H Operation

Basic Fusion Science



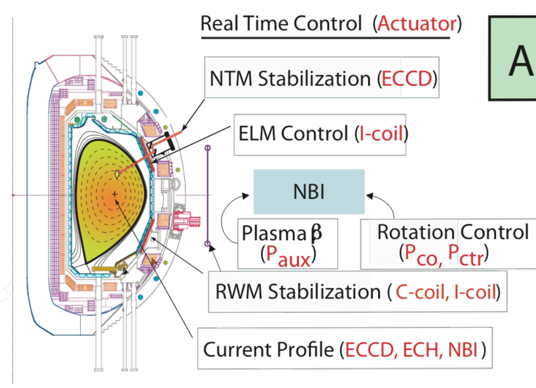
- L-H Transition
- Core Transport
- Plasma Rotation
- Fast Ions
- Stability

ITER Scenario Development



- Reference Scenarios
- ITER-relevant Startup and Rampdown
- High β Scenarios

Advanced Scenarios



- Integrated Scenario Development
- Core-Edge Coupling
- Instability Control

2010 DIII-D Experimental Campaign Organized in 4 Task Forces, 6 Physics Areas, and Torkil Jensen Award

Physics Groups within the Experimental Science Division

Task Forces	Steady-State Integration T. Luce	Integrated Modeling R. Prater	ITER Physics E. Strait	Plasma Control and Operations D. Humphreys	Fusion Science C. Petty	Plasma Boundary Interfaces A. Leonard
01 Rapid Shutdown Schemes for ITER E. Hollmann (UCSD) T. Jernigan (ORNL)	11 Assess Steady-State Current Profiles for Optimum Performance* J. Ferron C. Holcomb (LLNL)	21 Pedestal Structure R. Groebner P. Snyder	31 ELM Control for ITER T. Evans R. Moyer (UCSD)	41 ITER Scenario Access, Startup and Ramp Down G. Jackson	51 Rotation Physics W. Solomon (PPPL)	61 Hydrogen Retention S. Allen (LLNL)
02 Physics of Non-Axisymmetric Field Effects in Support of ITER H. Reimerdes (Columbia) O Schmitz (TEXTOR)	12 Core Integration (Advanced Inductive) P. Politzer	22 General IM R. Prater	32 Disruption Characterization and Avoidance J. Wesley	42 Integrated and Model-Based Control M. Walker	52 Energetic Particles (2010) W. Heidbrink (UCI)	62 Thermal Transport in the Plasma Boundary (2010) C. Lasnier (LLNL) J. Boedo (UCSD)
03 Transport Model Validation (TMV) T. Rhodes (UCLA) C. Holland (UCSD)	13 Core-Edge Integration T. Petrie		33 NTM Stabilization Including Rotation Dependence R. LaHaye	43 General PCO D. Humphreys	53 Transport G. McKee (U Wisc)	63 SOL Main Ion and Impurity Flows A. Leonard
04 Test Blanket Module (TBM) 2010 M. Schaffer, J. Snipes (ITER) C. Greenfield	14 RWM Physics including Rotation Dependence M. Okabayashi (PPPL)		34 ITER Demonstration Discharges E. Doyle (UCLA)		54 Stability R. La Haye	64 Physics of Volume Recombination and Divertor Detachment A. Leonard
09 Torkil Jensen Award D. Hill M. Wade	15 General SSI T. Luce		35 Hydrogen and Helium Plasmas P. Gohil		55 Heating & Current Drive R. Prater	65 General PBI A. Leonard
			36 General IP E. Strait		56 General FS C. Petty	

* Includes Core Integration (Steady-State Scenario)

- [yellow] FY10 Highest Priority Task Force or Working Group and Leaders
- [light blue] Other Working Groups and Leaders
- [green] Physics Groups and Leaders
- (****) Collaborator Affiliations as noted

- **Structure re-evaluated "yearly" by DIII-D Research Council**

2010 Run Time Allocation Roughly Balances Work in ITER Issues, Advanced Tokamaks and Fusion Science

Table 1: DIII-D run-time allocations.

Area or Task Force	17 Week
ITER Physics	10
Steady State Integration	13
Fusion Science	10
Integrated Modeling and Pedestal Structure	4
Plasma Control	3.5
Plasma Boundary Interfaces	6.5
ITER TBM Tokamak Physics (TF)	4
Rapid Shutdown for ITER (TF)	4
Physics of 3D Fields for ITER (TF)	5
Transport Model Validation (TF)	3
Total days for planned experiments	63
DIII-D Director's Reserve	5

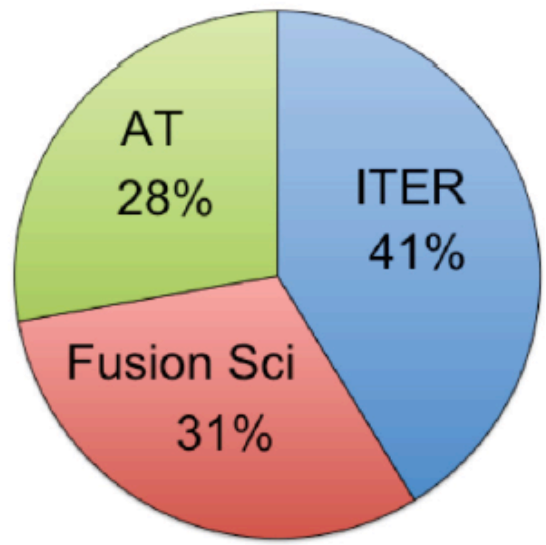
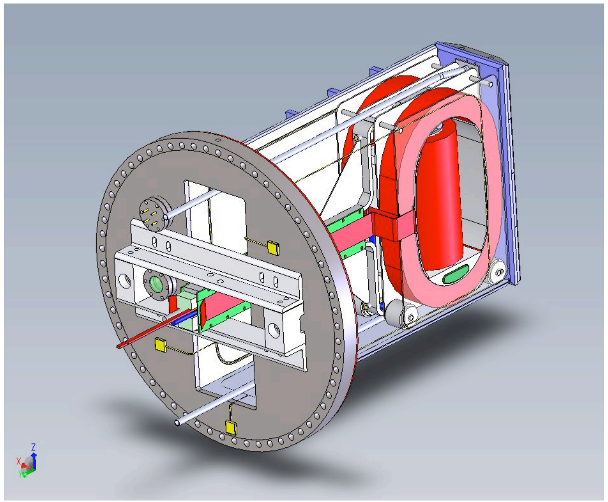


Fig. 1. Allocation of run time for 17 operating weeks, organized by primary emphasis of proposed experiments: R&D for ITER, Advanced Tokamak development, and Fusion Science.

- **Anticipate trend toward increased emphasis on AT and Fusion Science as ITER enters construction phase.**

Task Force Plans Include Work with the ITER Test Blanket Module (TBM) Mock-up and Rapid Shutdown Schemes

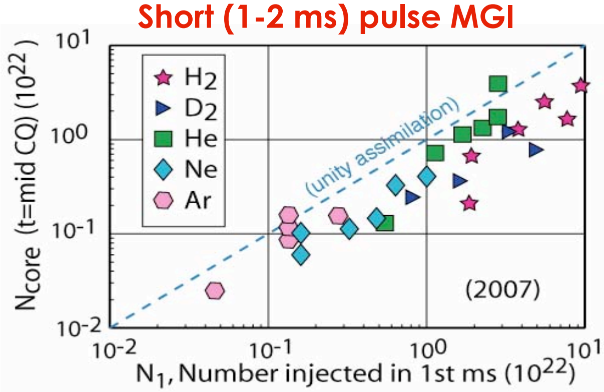
- TBM Task Force [4 days] – M. Schaffer, J. Snipes - ITER IO, (C. Greenfield)
  - General Survey of TBM Effects on H-mode Operation
  - Effect of TBM Magnetic Perturbation on:
    - Confinement & Transport - NSTX interactions
    - L-H Power Thresholds - NSTX interactions
    - RMP ELM Suppression
    - Fast Ion Confinement
    - Error Fields and Locked Mode Thresholds
  - On-site collaboration with large (~12 member) international team including D. Gates (NSTX)



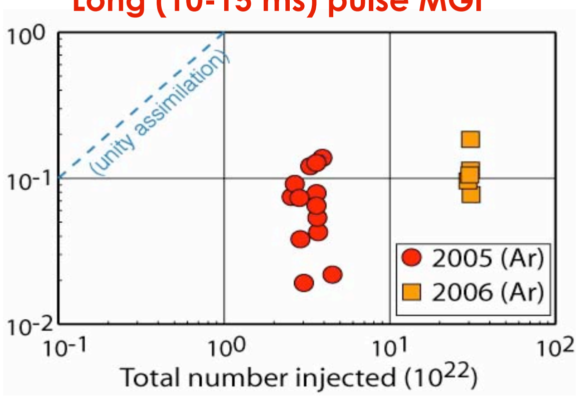
- Rapid Shutdown for ITER [4 days] – E. Hollmann (T. Jernigan)
  - Multiple schemes will be tested:
    - Neon and D2 Shattered Pellets
    - Impurity Injection into Runaway Electron Beam
    - Large Shell Pellets
    - RMP Runaway Suppression

Multiple Schemes for Rapid Plasma Shutdown and Runaway Electron Mitigation Were Demonstrated and Compared

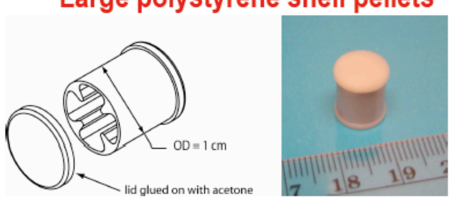
Short (1-2 ms) pulse MGI



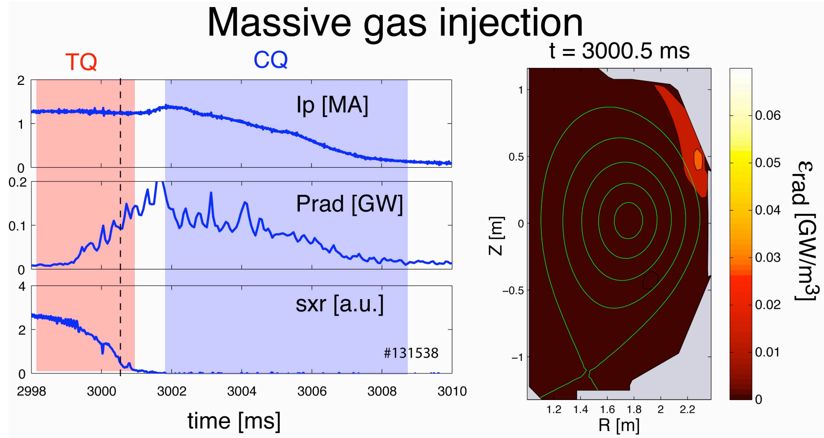
Long (10-15 ms) pulse MGI

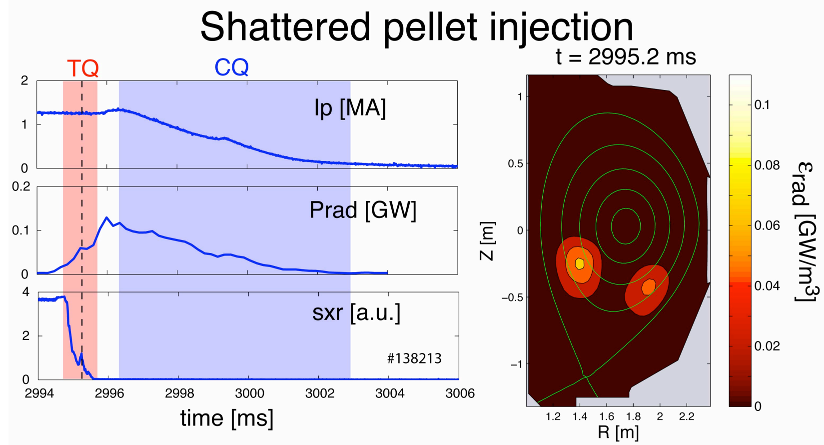


Large polystyrene shell pellets



- He MGI particle assimilation optimized at ~ 2 ms in DIII-D
- Shattered D2 pellet provided very rapid TQ and high n_e
- Large Shell Pellets penetrated through DIII-D plasma
- RMP fields (n=3) de-confine runaway electron beams





DIII-D NATIONAL FUSION FACILITY

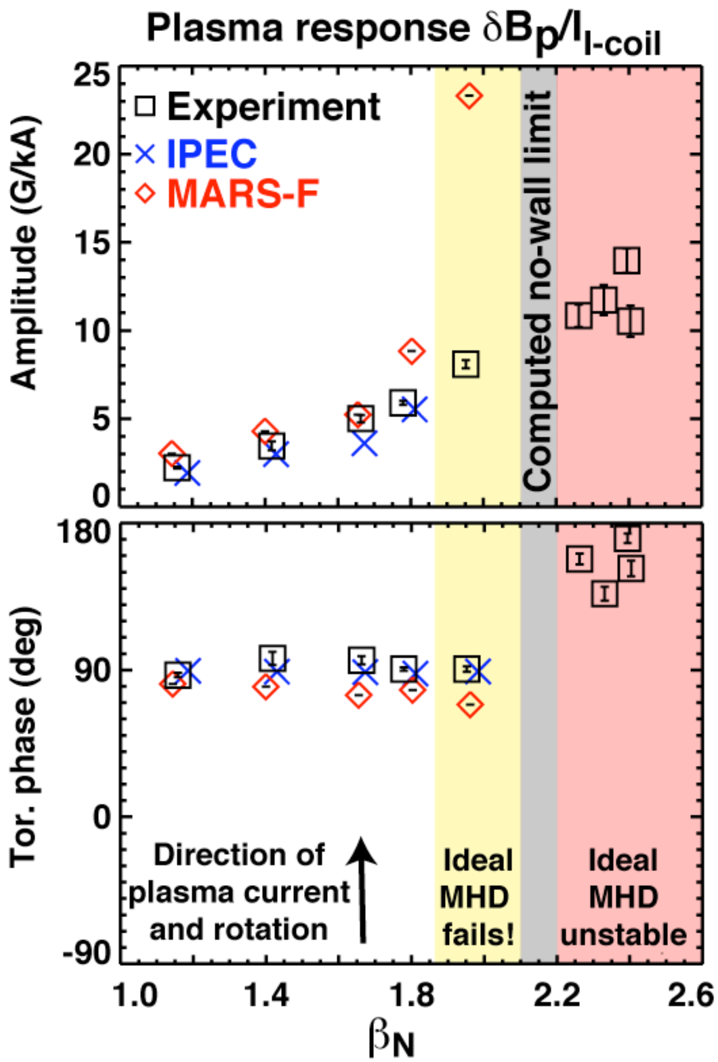
E. Hollmann, Post Deadline Invited Friday am
N. Commaux, Oral Thurs pm, V. Izzo this session

Task Force Plans Include Studies of 3D Field Effects and Transport Model Validation

- **3D Fields for ITER [5 days] – H. Reimerdes (O. Schmitz – FZJ, Juelich)**
  - **Error Field Threshold - NTV vs Torque Balance Limits - NSTX interactions**
  - **3D Characteristics in Low Power H-modes**
  - **Test NTV Theory of Non-Resonant Magnetic Fields - NSTX interactions**
  - **RMP ELM Suppression with no/low counter rotation**
  - **Edge Harmonic Oscillation (EHO) Induced Transport**
  - **Enhanced Particle Transport with RMPs Error Field Thresholds**

- **Transport Model Validation [3 days] – T. Rhodes (C. Holland)**
  - **Dependence of multi-field turbulence properties and transport on Te/Ti**
  - **Test of simulations in high confinement, quiescent regime, QH-mode**

Linear ideal MHD theory describes measured *n*=1 plasma response for values of beta up to 70% of no-wall stability limit



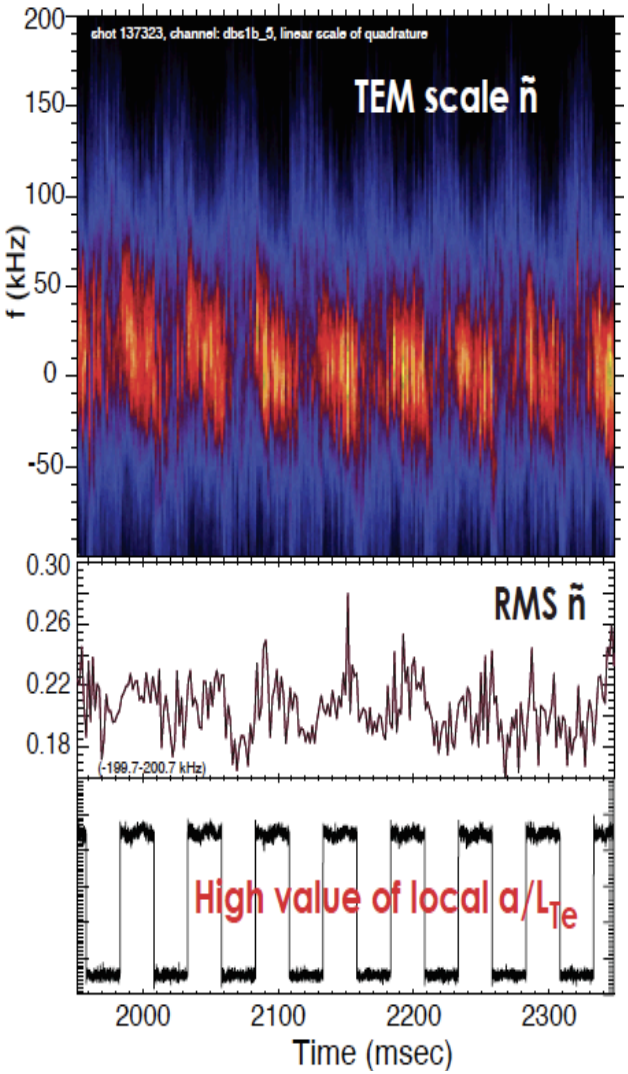
… but ideal theory fails at higher β_N

- Probe rotating H-mode plasmas with externally applied *n*=1 fields
- For $\beta_N < 1.7$ ideal MHD models (MARS-F, IPEC) predict the perturbed field to within 20%
  - Good agreement found at multiple poloidal and toroidal locations
- For higher β_N, non-ideal effects modify response
  - Plasmas remain stable above the ideal MHD no-wall stability limit
  - Calculated response amplitude diverges near marginal stability
- A validated model of the plasma response to external fields is essential for understanding the error field threshold, testing magnetic braking theory, etc.

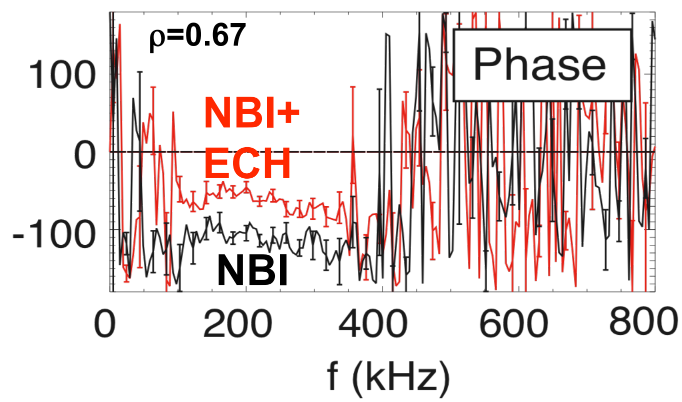
DIII-D NATIONAL FUSION FACILITY

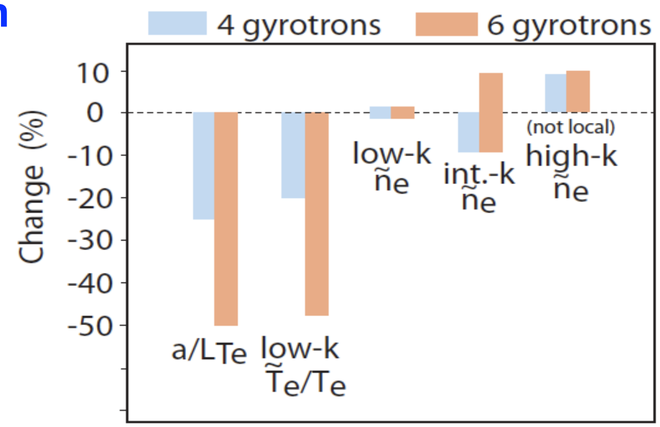
M. Lanctot this session

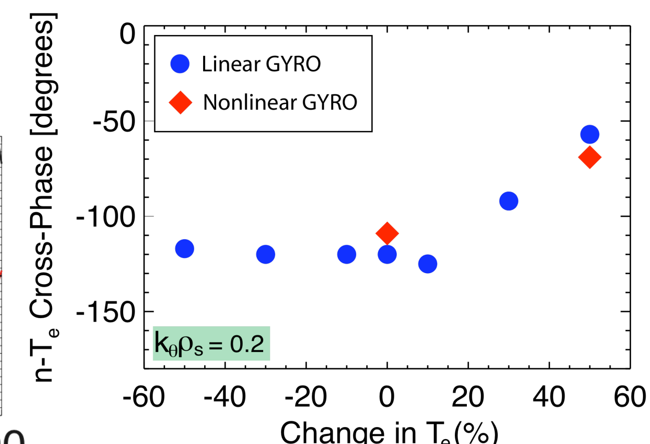
ECH Used to Modulate Local Value of ∇Te and a/L_{Te} To Isolate and Test Electron Mode Physics in Turbulence Simulations



- **Isolates and tests electron mode physics**
  - **Electron modes (TEM and ETG) dominate ITG modes**
- **Multiple broad k-range fluctuation fields show complex response that will constrain simulations**
- **Predicted variation of n_e-T_e cross phase validated by measurements**







J . DeBoo, Invited Tues pm
J. Candy, Invited Mon pm

ITER Physics and Plasma Control and Operations Areas Address ITER Urgent Issues

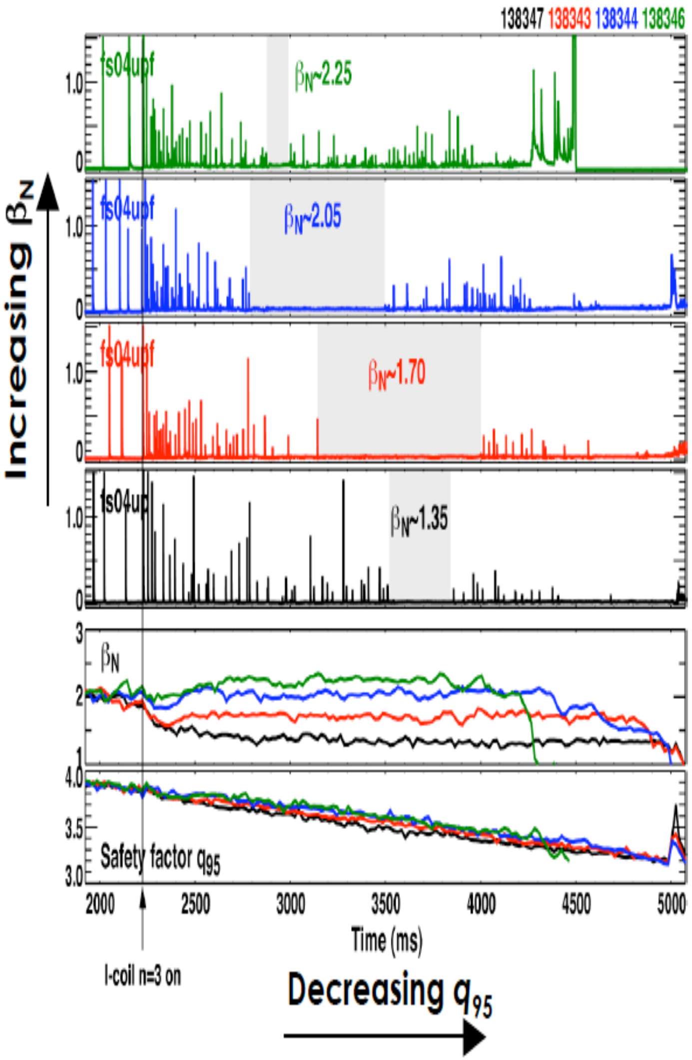
ITER PHYSICS [10 days] – T. Strait (R. LaHaye)

- ELM Control for ITER
  - 3D heat flux during RMP ELM control
  - RMP effect on L-H power threshold and first ELM
  - ELM pacing with AC RMP - NSTX interactions
  - Interaction of pellets and ELMs
- Disruption Characterization and Avoidance
- NTM Suppression
- ITER Demonstration Discharges
- Hydrogen and Helium Plasmas – Hydrogen beams into He plasma (2010)

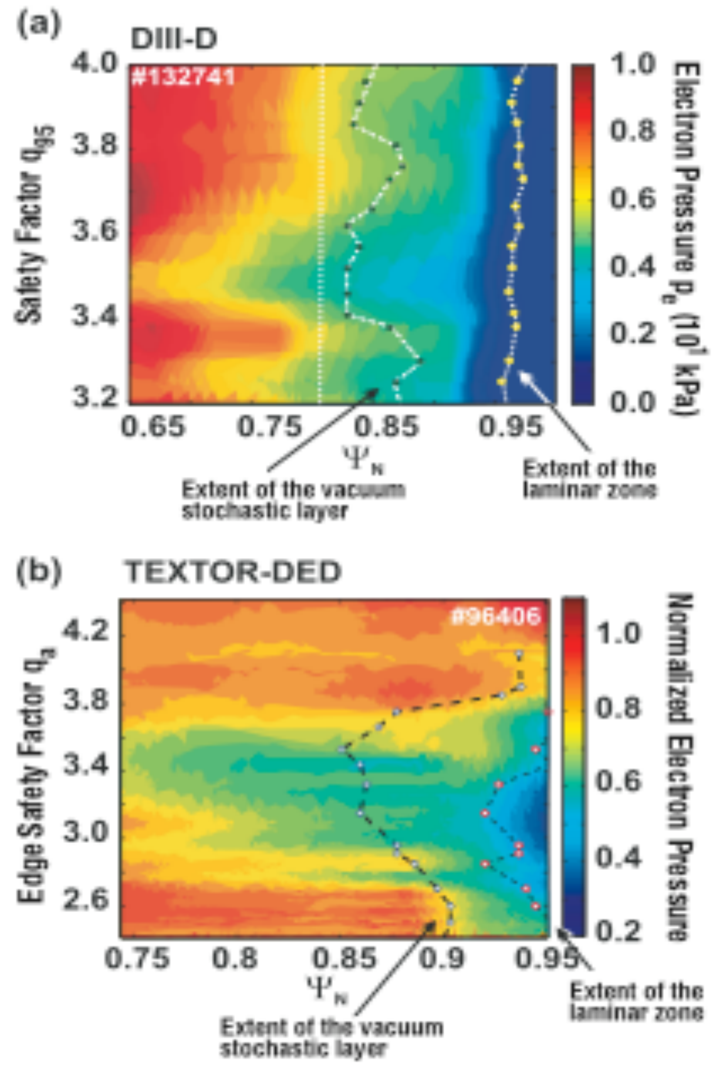
PLASMA CONTROL AND OPERATIONS [3.5 days] – D. Humphreys (M. Walker)

- ITER Scenario Access - Start-up and Rampdown
  - ITER Rampdown Scenarios Beyond the Baseline
  - Improved Startup Scenarios for ITER
- Integrated Model Based Control

Plasma Response to Resonant Magnetic Perturbation (RMP) Fields Affects q_{95} Window for ELM Suppression

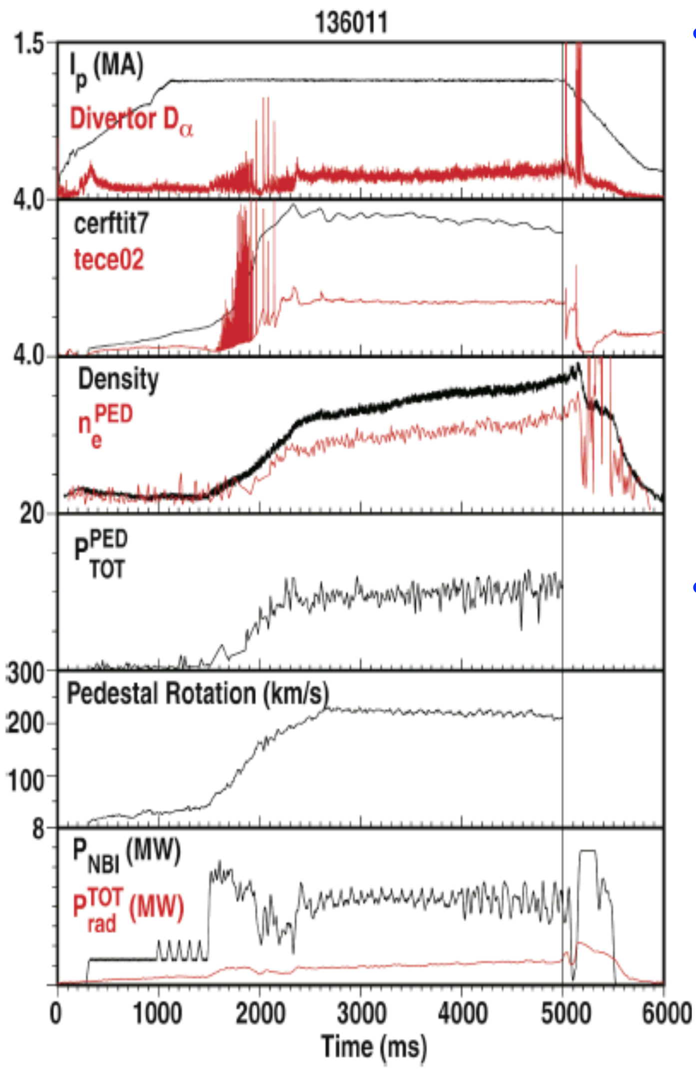


- ELM suppression window shifts to higher q_{95} with higher β_N
- Largest q_{95} window for ELM suppression at intermediate β_N
- Resonant response of pedestal T_e also seen during q_{95} scans with RMP ELM suppression



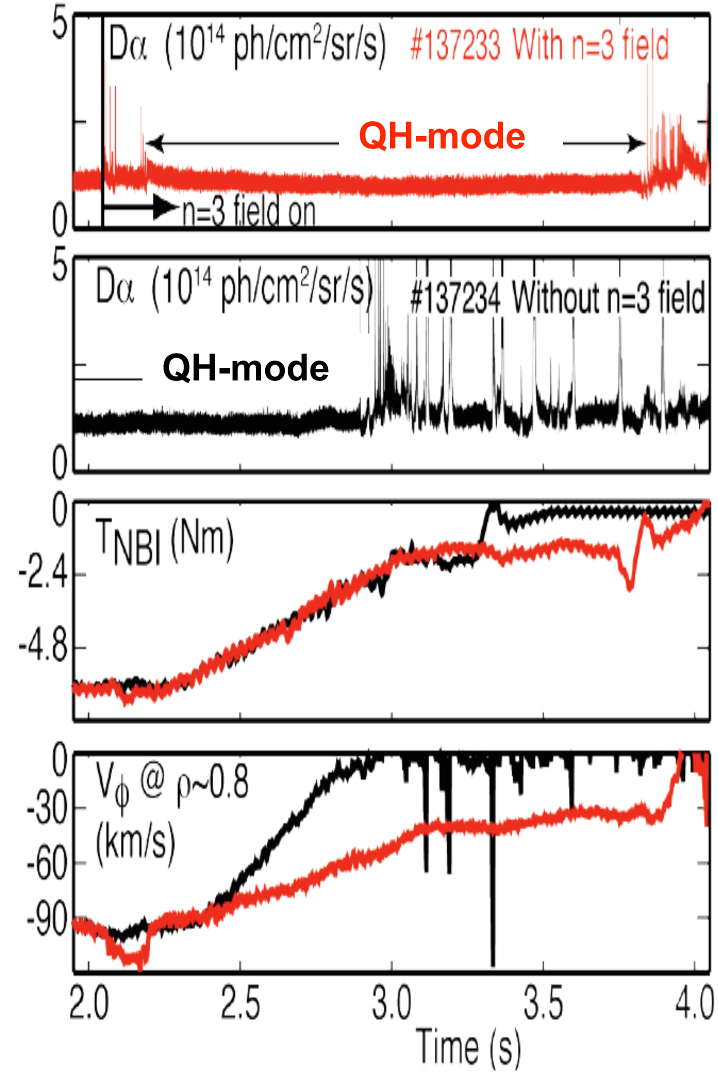
O. Schmitz, S. Mordijck this session, Posters Tues pm

QH-mode Operating Space Extended With Co-NBI and to Low NBI Torque Regimes With Non-Resonant Fields



- **QH-mode with co-NBI extended to available beam pulse**
  - **Co-directed V_{rot} high**
  - **P_{rad} low**

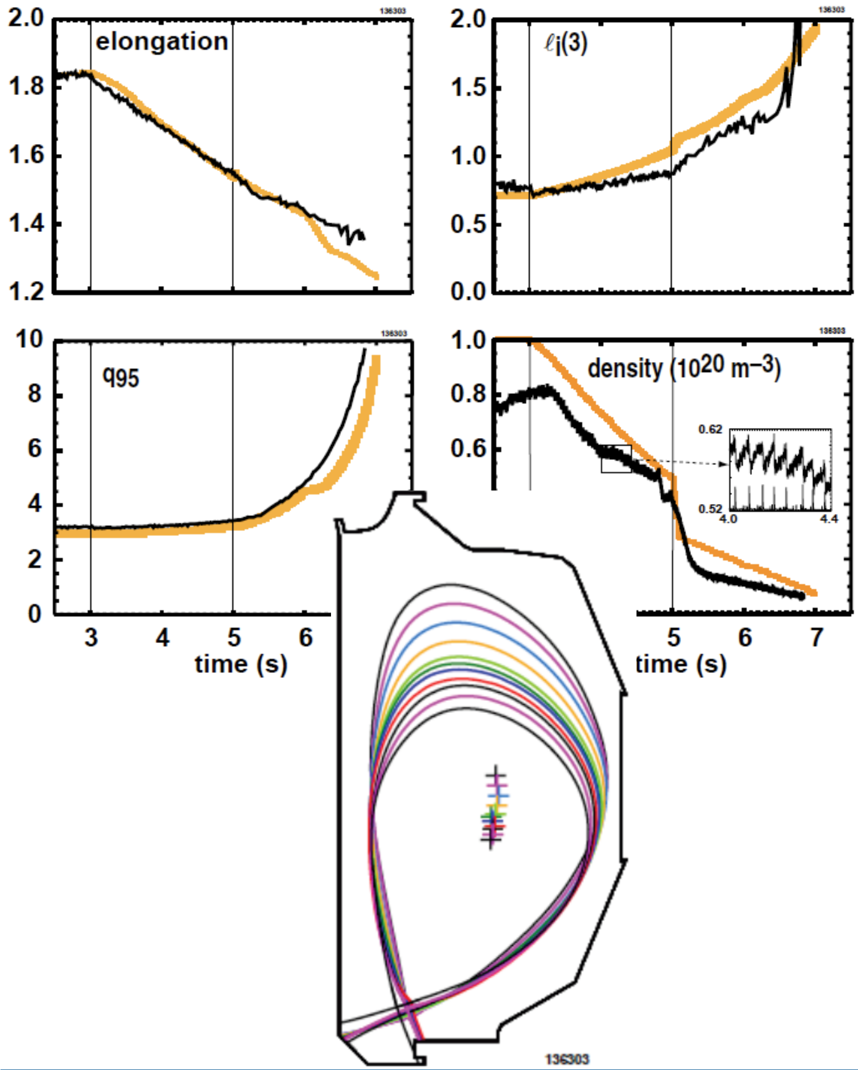
- **Torque from predominantly non-resonant magnetic fields extends QH-mode to low NBI input torque regimes**
  - **NTV theory**



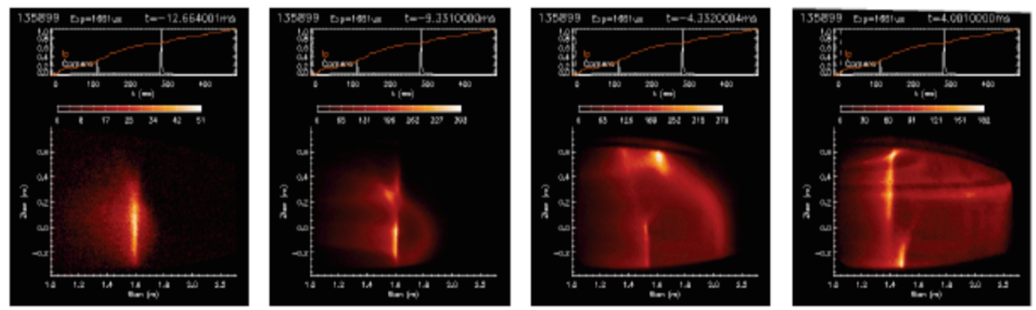
DIII-D NATIONAL FUSION FACILITY

A. Garofalo, Z. Yan, this session
Posters Thurs am

Plasma Startup at Low ITER-like Voltage and ITER Rampdown Scenarios Demonstrated



- Low voltage (V_L=3V, E_T=0.3 V/m) startup with ITER geometry and ECH assist demonstrated
- ITER scenario rampdown demonstrated
  - H-L transition without disruption
  - DINA simulation validated



t= -12.7 ms, I p =1.8 kA, V_L= 0V (Breakdown near X2 resonance)

t= -9,3 ms, I p =1.9 kA, V_L= 0V (CIII Light expands)

t= -4.3 ms, I p =5.6 kA, V_L= 0.6V (Further expansion with V_L)

t= +4.0ms, I p =25kA, V_L=2.6V (Closed flux, starts inward)

t= 12 ms, I p 61kA, V_L= 3.0V (Limits on Inner Wall)

t= 39 ms, I p 98kA, V_L= 3.0V (Limits on Outer Wall)

t= 360ms, I p =510 kA, V_L=1.3V (Diverted)

R_{IW}(midplane) = 1.02 m
R_{X2} = 1.64 m
R_{OW}(midplane)=2.36m
B_ϕ=1.9T, V_L=3V, $B_{V,pgm}$=-30G
$C^{III}_{ionization}$ = 48 eV
$C^{III}_{burnthrough} \approx$ 16-24 eV

G. Jackson Invited Thurs am,
P. Politzer Oral, Thurs pm, J. Leuer this session

Pedestal, SOL and Divertor Physics Done by Integrated Modeling and Plasmas Boundary Interfaces Physics Areas

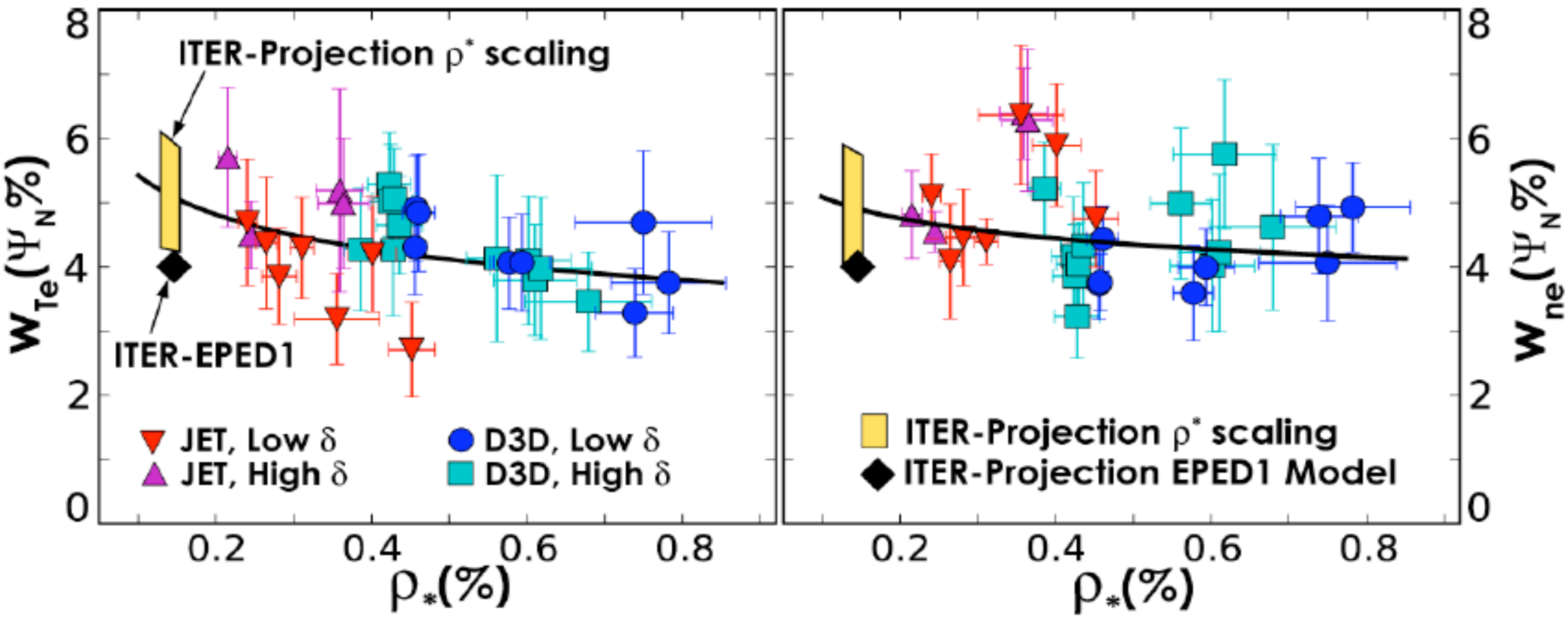
INTEGRATED MODELING [4 days] – R. Prater (R. Groebner)

- Pedestal Structure – R. Groebner, P. Snyder
  - Effect of collisionality on pedestal height, ELM size and turbulence
  - Role of gyrokinetic modes in limiting pedestal structure
  - Effect of edge rotation on pedestal height, ELM size and turbulence
  - Matching experiment with C-Mod Type I ELMing regime

PLASMA BOUNDARY INTERFACES [6.5 days] – T. Leonard (S. Allen)

- Hydrogen Retention – 2009 Joint Facility Milestone with NSTX and CMOD
- Thermal Transport in the Plasma Boundary – 2010 Joint Facility Milestone with NSTX and CMOD - NSTX interactions
  - Heat flux measurements of the divertor and SOL
  - C-Mode heat flux comparison
  - Divertor Heat flux scaling
  - SOL heat flux characterization in USN
- SOL Main Ion and Impurity Flows
- Physics of Volume Recombination and Divertor Detachment

Factor of 4 Variation of ρ* in DIII-D and JET Shows Essentially No Dependence of Pedestal Widths on ρ*

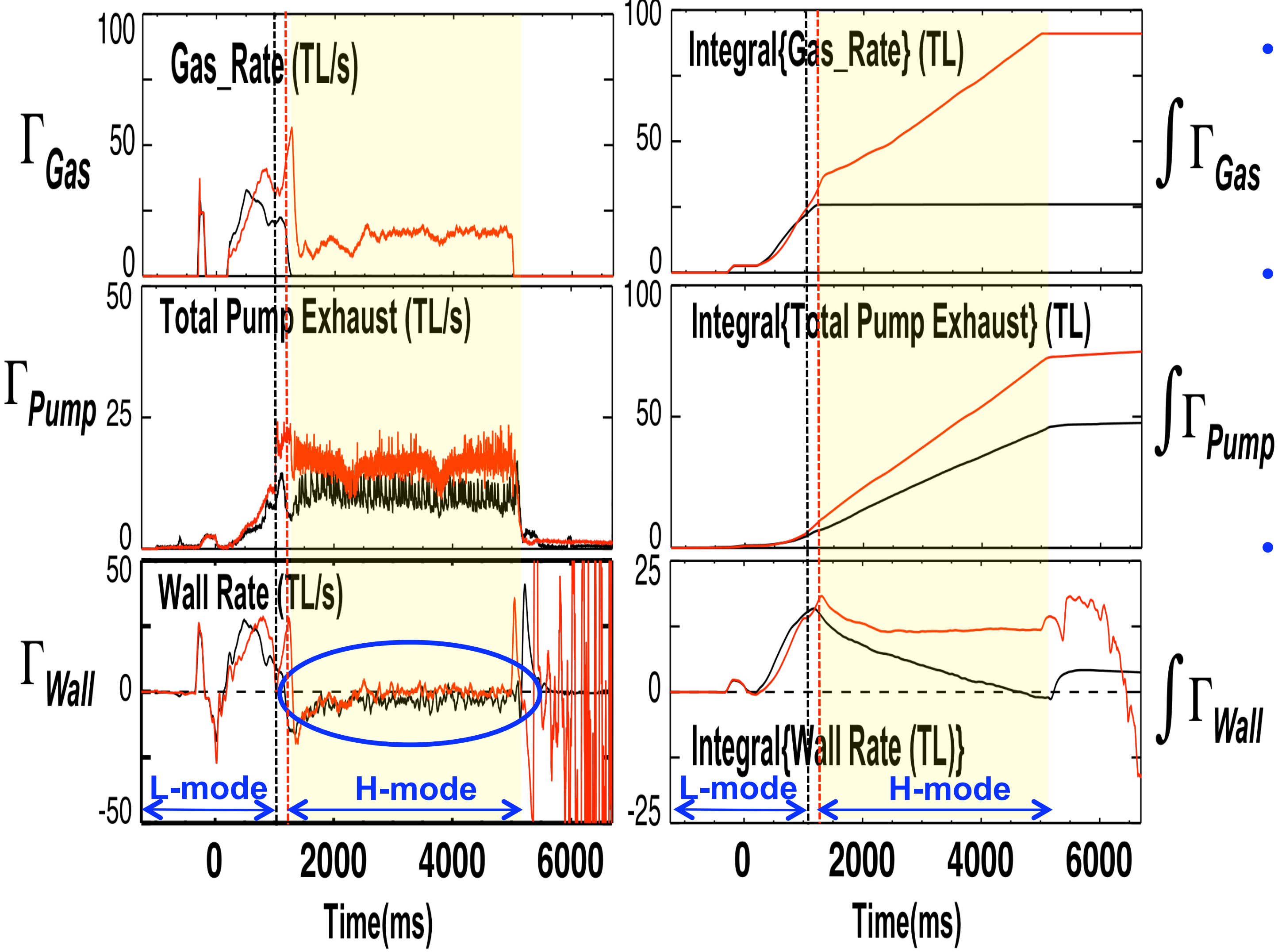


- Fits of widths in Ψ_N give weak inverse dependence on ρ_*
  - Much weaker and in opposite direction than $(\rho_*)^{1/2}$ or $(\rho_*)^1$ as predicted by several theories
- Potentially good news for ITER scenarios with small ρ_*

M.A. Beurskens, T.H. Osborne et al., PPCF (2009)

T.H Osborne this session

Detailed Particle Balance Showed Large Wall Uptake in L-mode and Very Low Uptake in H-mode



- Low wall uptake in H-modes with ECH or NBI
- ITER tritium retention estimates may be reduced
- Static and dynamic particle balance methods agree
  - ECH H-mode: within +-5%
  - NBI H-mode: within +- 12%

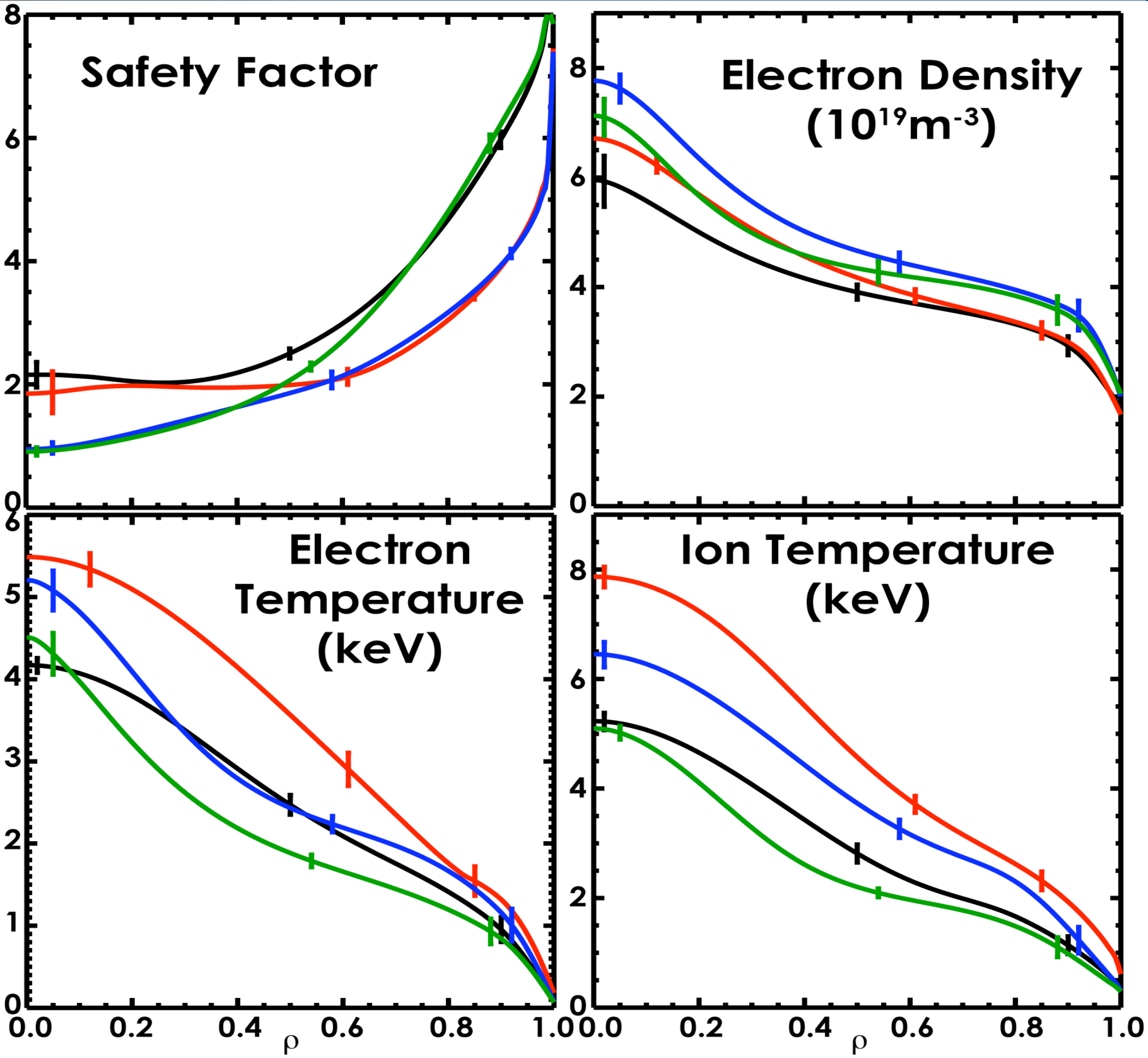
S.L. Allen this session

Steady State Integration Area Includes Work on Hybrid, Advanced Tokamak and Integrated Scenarios Development

STEADY STATE INTEGRATION [13 days] – T. Luce (J. Ferron)

- **Assess Steady State Current Profiles for Optimum Performance**
  - **Fully non-inductive development**
  - **Resistive MHD avoidance in steady-state scenarios**
  - **Stationary fully non-inductive operation**
- **Core Integration**
  - **EC+FW Advanced Inductive development**
  - **FW coupling development - NSTX interactions**
- **Core-Edge Integration**
  - **Radiative divertor + RMP ELM suppression, Reversed BT**
  - **High Performance hybrid + RMP ELM suppression**
- **RWM Physics including Rotation Dependence – NSTX interactions**
  - **Current Driven RWM feedback development**
  - **Fishbone Driven Energetic particle interaction with RWMs**
  - **AC compensation for feedback**

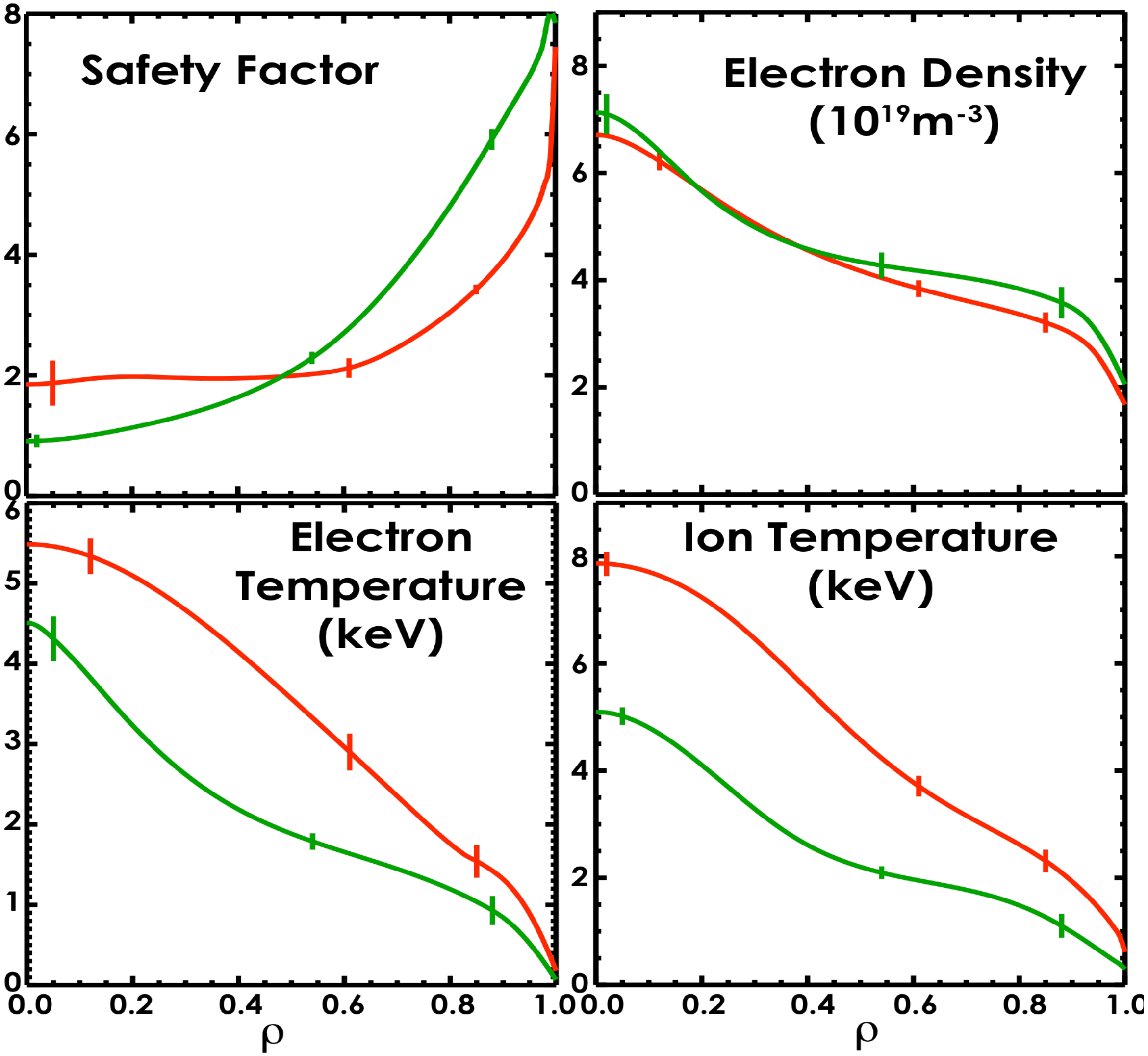
Systematic variation of n_e, T_e, and T_i profiles seen at fixed β_N with q_{min} and q_{95} variation in Advanced Tokamak scenarios



- **Fully relaxed averaged profiles**

		q_{95}	q_{95}
		4.5	6.8
q_{min}	2	136837	136835
q_{min}	1.1	136854	136853

Systematic variation of n_e, T_e, and T_i profiles seen at fixed β_N with q_{min} and q_{95} variation in Advanced Tokamak scenarios



- Fully relaxed averaged profiles

		q_{95}	q_{95}
		4.5	6.8
q_{min}	2	136837	136835
q_{min}	1.1	136854	136853

- As q_{95} reduced:
  - Higher n_e, T_e, and T_i
  - Lower f_{bs}
- As q_{min} reduced:
  - n_e higher and more peaked
  - T_e more peaked
  - Improved stability
  - T_i lower

DIII-D NATIONAL FUSION FACILITY

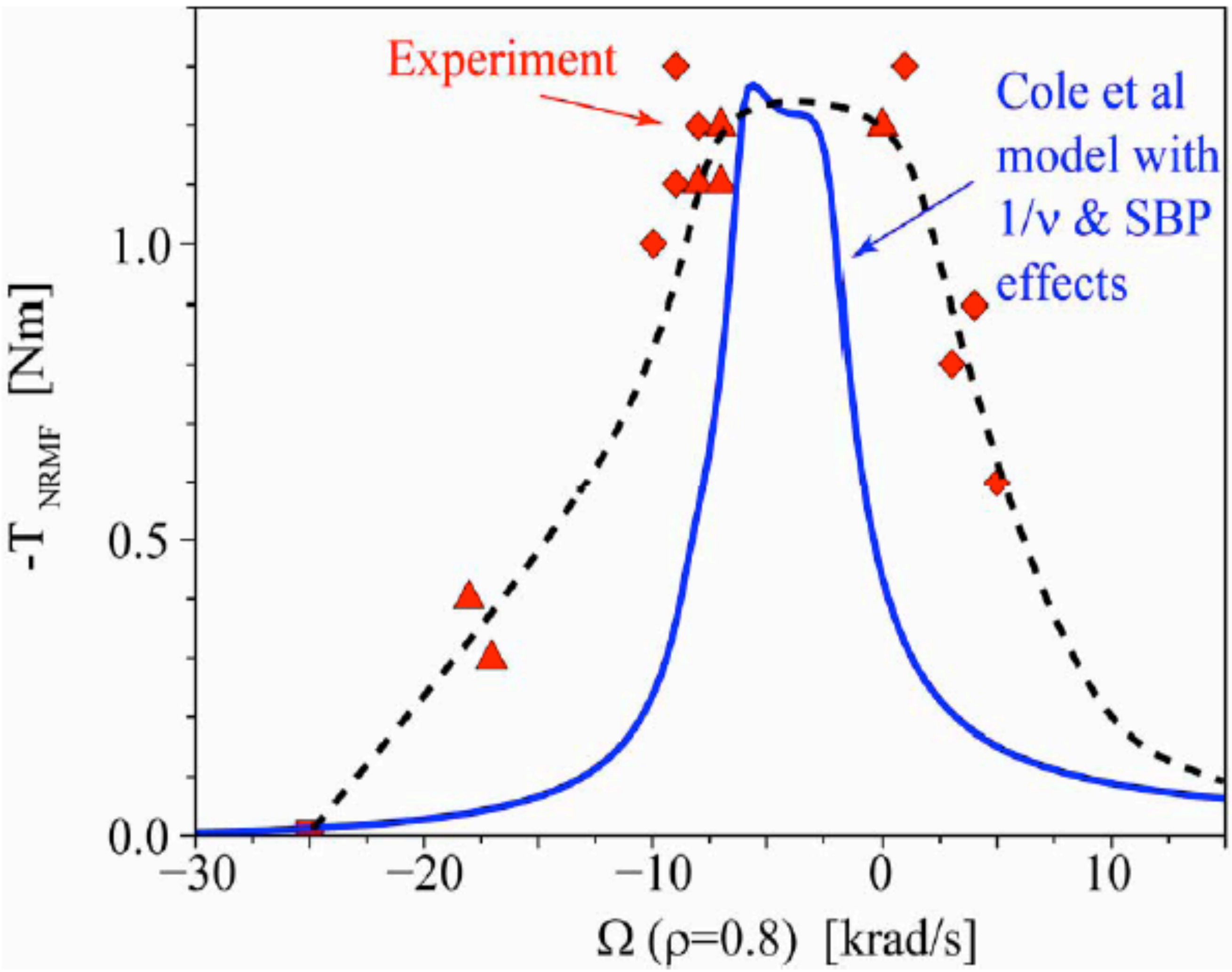
T. Luce Review Mon am
C. Holcomb this session

Fusion Science Area Contains Multiple Topics to Advance Plasma Physics on a Broad Front

FUSION SCIENCE [10 days] – C. Petty (C. Greenfield)

- **Rotation Physics**
  - **Investigation of intrinsic rotation drive by turbulence-driven Reynolds Stress**
  - **Cross machine comparison between DIII-D and NSTX on role of aspect ratio on poloidal rotation - NSTX interactions**
- **Energetic Particles**
  - **Fast-ion transport by many RSAEs and TAEs - NSTX interactions**
  - **Fast-ion transport by NTMs and at sawtooth crashes - NSTX interactions**
  - **Stability and transport of low frequency Alfven modes that interact strongly with thermal ions - NSTX interactions**
  - **Transport of super-Alfvenic fast ions and comparison with NSTX - NSTX interactions**
- **Transport**
  - **The role of zonal flows and Reynolds Stress in triggering the L-H transition**
  - **Turbulence pinch and diffusion mechanisms behind the ν^* and η_e dependence of particle transport**
- **Stability**
- **Heating and Current Drive**

Evidence Found for Increased Torque in 1/ν Regime in Agreement with Neo-classical Toroidal Velocity Theory



- **Torque from non -resonant fields deduced from input NB torque required to hold rotation constant**
- **Magnitude of torque peak in 1/ν regime similar to theory**
- **Width of torque peak larger than predicted**
  - **Theory development in progress**

W. Solomon Invited Weds am
Posters Thurs am

Torkil Jensen Award for Innovative Research Available to Stimulate "Out of the Box" Ideas

- Proposals evaluated by TJA committees:
  - 2009: K. Burrell (GA), M. Mauel (Columbia), R. Fonck (U. Wisc.)
  - 2010: D. Hill (LLNL), K. Burrell (GA), M. Mauel (Columbia)

- 2009 TJA Experiments
  - Solenoidless Startup – G. Cunningham (UKAEA), J. Leuer (GA)
    - NSTX interactions
  - Super-H-mode – P. Snyder

- 2010 TJA Experiments
  - Effect of TBM on QH-mode at Low Input Torque – A. Garofalo
  - To Be Announced

Experimental Physics for 17 weeks in 2010 Followed by LTO-II for Off-Axis NBI and Center Post RMP Coils

PROPOSED DIII-D FY2010 OPERATIONS SCHEDULE

Oct

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Nov

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	H	H	28
29	30					

Dec

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	H	H	26
27	H	H	H	H		

Jan

S	M	T	W	T	F	S
					H	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Feb

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

Mar

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Apr

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

May

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

Jun

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

Jul

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Aug

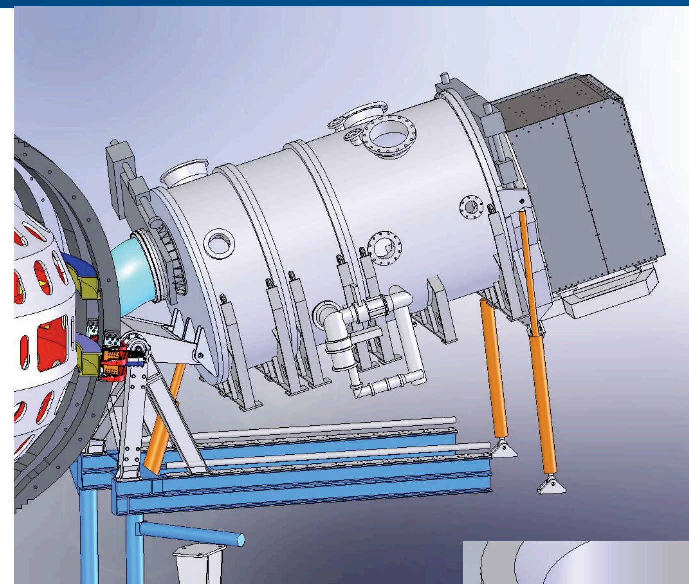
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Sep

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

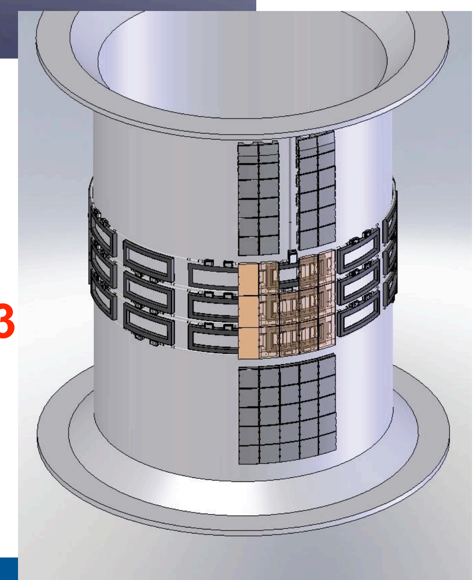
Plasma physics | Startup | Option | Vent

Plasma Physics extended days (8:30 AM - 8:00 PM)



2011 Campaign

- **Restart April 21**
- **Physics Expts May 16 – Sept 23**



Further Information: https://diii-d.gat.com/diii-d/Exp10

Or contact me at: fenstermacher@fusion.gat.com