SUMMARY of

STABILITY and ENERGETIC PARTICLES

WAVES and CURRENT DRIVE

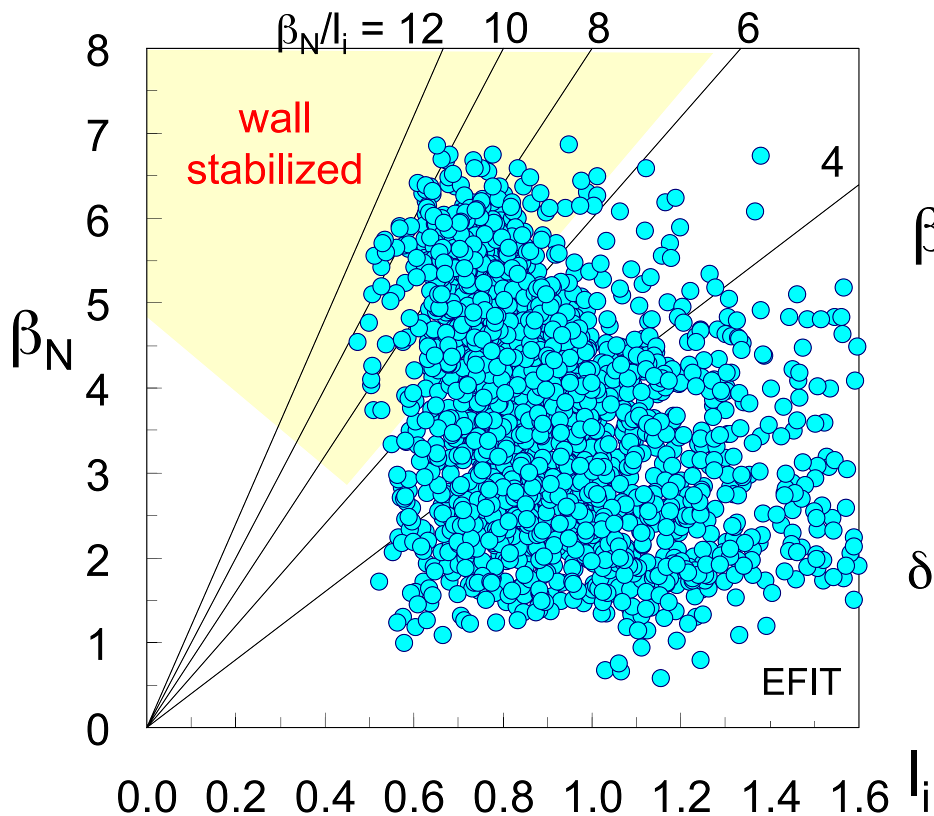
IAEA 2004

R. D. Stambaugh

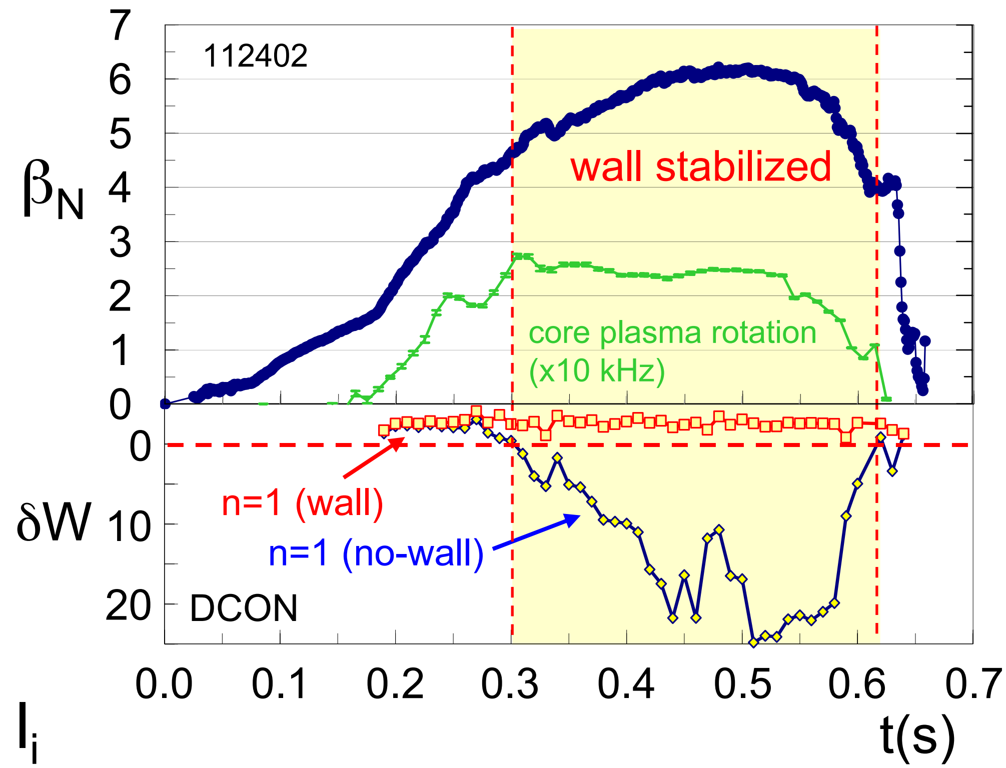
SUBJECT	PAPERS
RWM	7
Disruptions	6
NTM	6
ELMS, Pedestal	13
Other Stability	9
Alfven Modes	9
Wave Physics	10
Current Drive	5
Total	65

Wall stabilization physics understanding is key to sustained plasma operation at maximum β

- High β_t = 39%, β_N = 6.8 reached



- Operation with $\beta_N/\beta_N^{no\text{-}wall}$ > 1.3 at highest β_N for pulse >> τ_{wall}



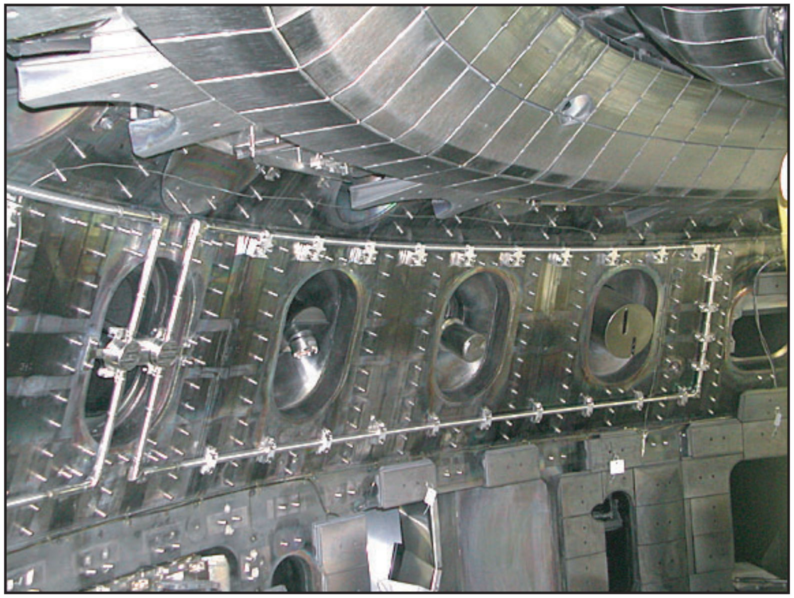
- Global MHD modes can lead to rotation damping, β collapse
- Physics of sustained stabilization is applicable to ITER

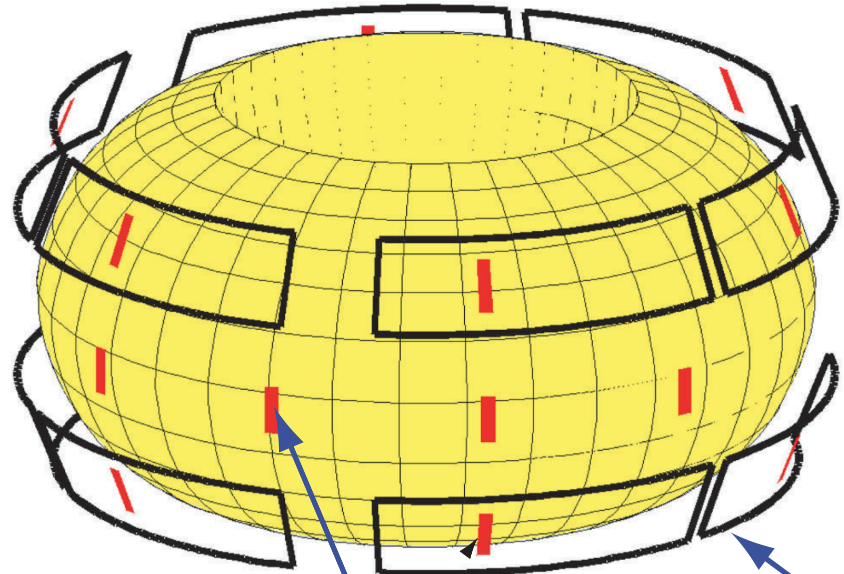
NSTX

Sabbagh, EX/3-2

NEW INTERNAL CONTROL COILS ARE AN EFFECTIVE TOOL FOR PURSUING STABILIZATION OF THE RWM

- Inside vacuum vessel: Faster time response for feedback control
  Closer to plasma, flexible magnetic field pattern: more efficient coupling





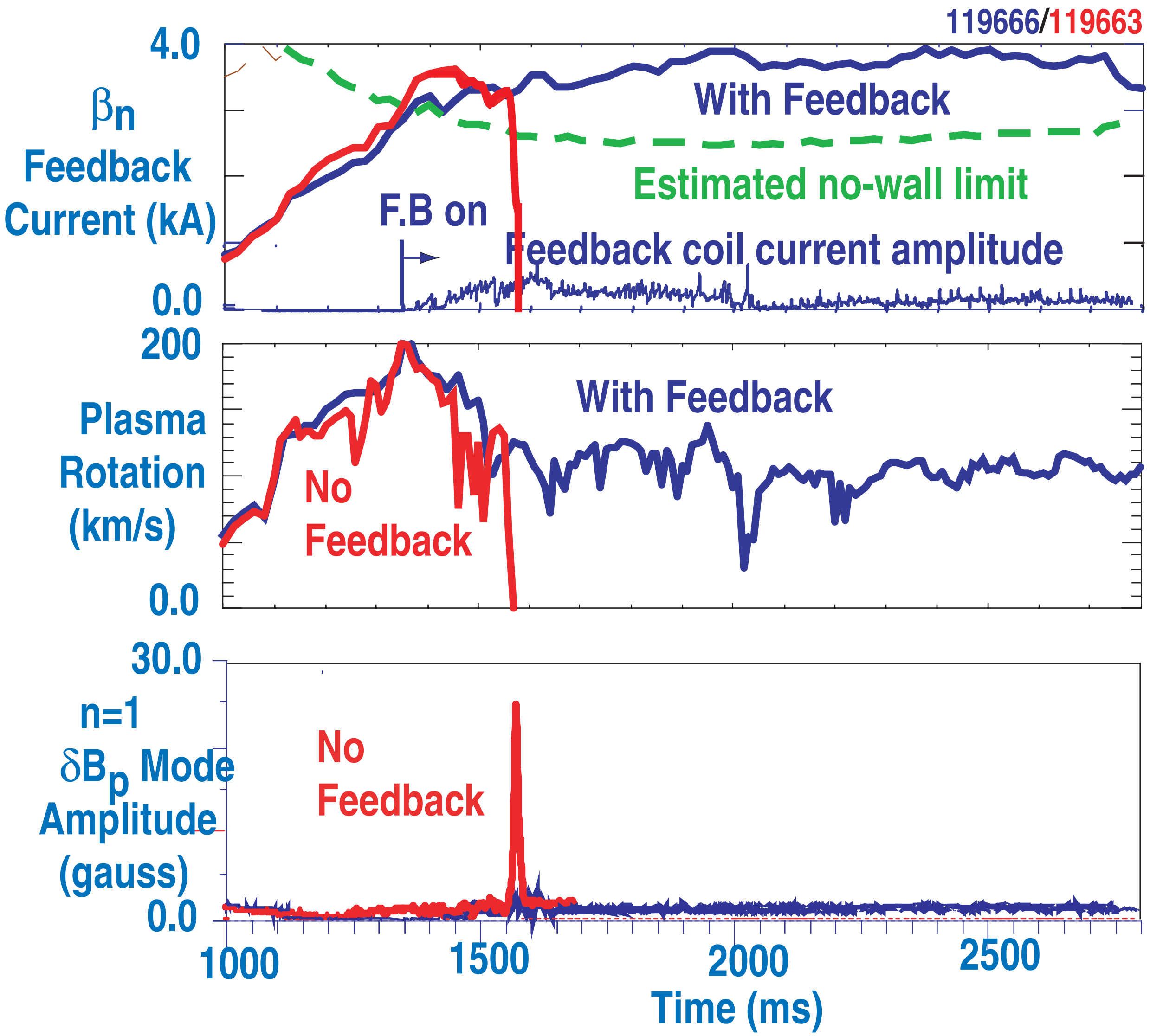
- 12 "picture-frame" coils
- Single-turn, water-cooled
- 7 kA max. rated current
- Protected by graphite tiles
- 10 gauss/kA on plasma surface

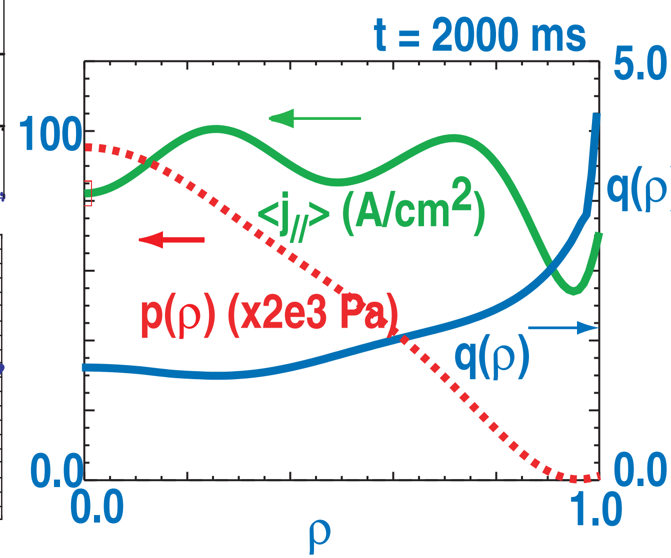
Okabayashi EX/3-1Ra
Reimerdes EX/3-1Rb

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

269-04/MO/jy

RWM FEEDBACK ASSISTS IN EXTENDING $\beta_N \approx 4$ ADVANCED TOKAMAK DISCHARGE MORE THAN 1 SECOND





Okabayashi EX / 3-1Ra
Reimerdes EX / 3-1Rb
see also Ferron EX/P 2-21
"Optimizing the Beta Limit in DIII-D"

DIII-D
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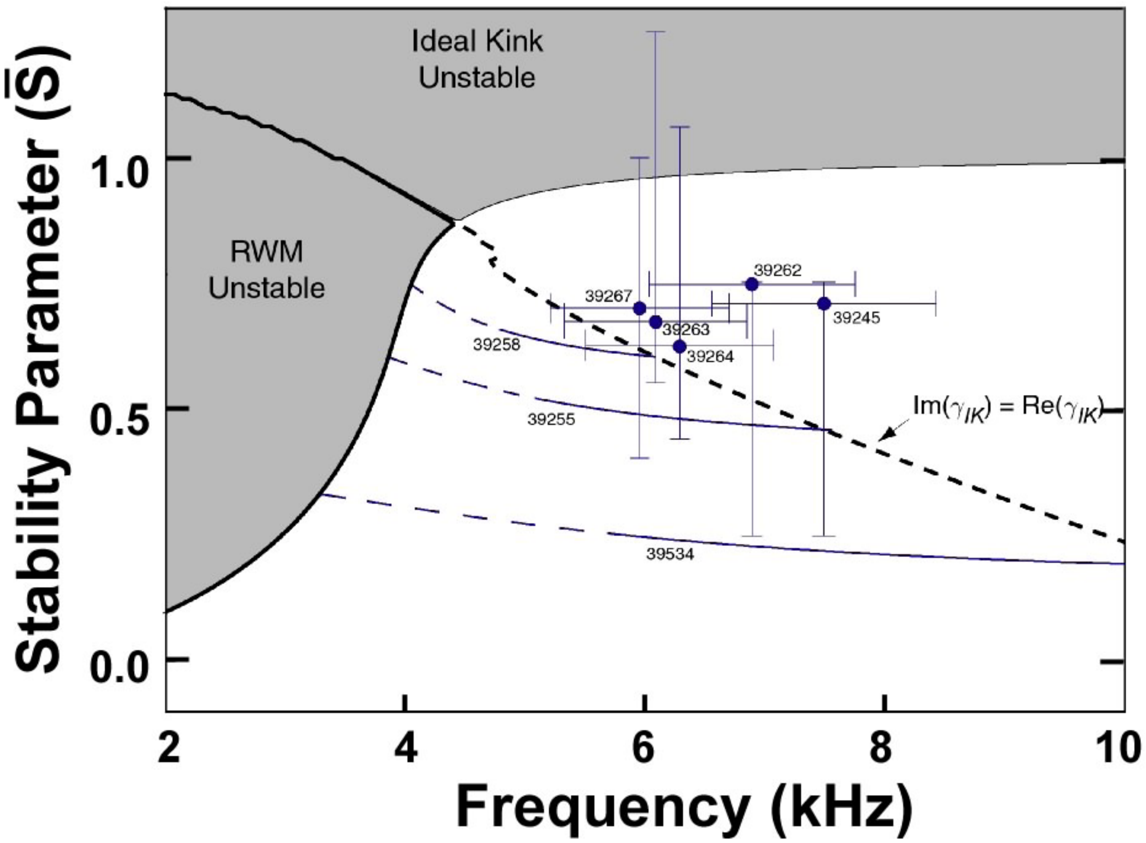
SAN DIEGO

- The rotation is similar for both cases

269-04/MO/jy

Both the ideal kink and RWM mode branches must be considered in feedback dynamics



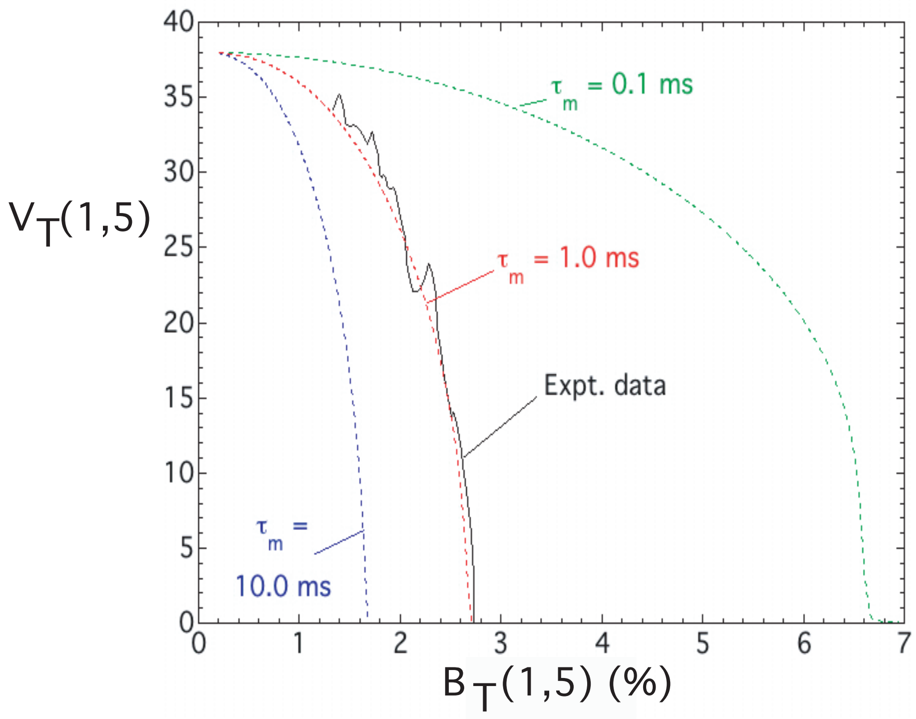
Discharge #	■ Estimate	τ_r (ms)	f_r (kHz) ± 1 kHz
39262	0.50 ± 0.25	0.70 ± 0.2	5.5
39263	0.92 ± 0.33	0.50 ± 0.15	5.1
39267	0.72 ± 0.30	0.50 ± 0.15	4.8
39245	0.51 ± 0.25	0.60 ± 0.2	6.1
39264	0.75 ± 0.31	0.43 ± 0.15	5.3
39258	0.24 ± 0.20	0.23 ± 0.1	< 4.0
39534	0.11 ± 0.15	0.15 ± 0.1	< 6.5
39255	0.22 ± 0.18	0.30 ± 0.1	< 3.5

- Coupled kink-wall mode system has two weakly damped roots in rotationally-stabilized regime.
- At low *s*, response decays quickly.
- Near ideal-wall limit, rotating plasma root decays slowly and phase-oscillations indicate plasma root's real frequency.

WALL STABILIZATION IN THE RFP

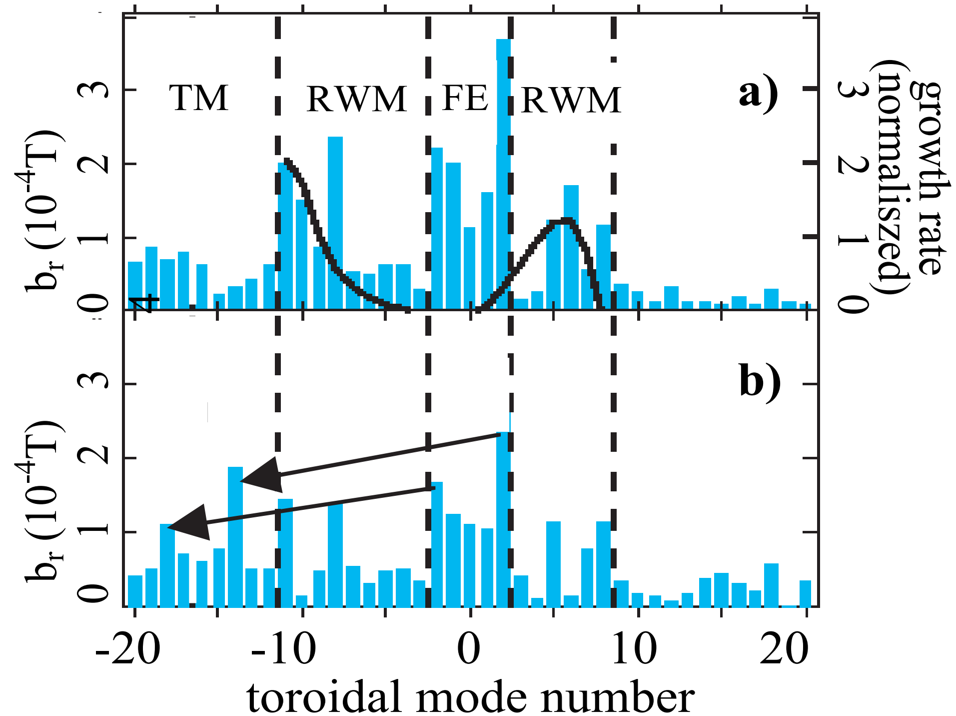
MST: test theory of mode locking by wall eddy currents

One free parameter:
momentum confinement time



Experiment consistent with theory

EXTRAP T2R: Feedback coils (16 toroidal and 4 poloidal) suppress a spectrum of unstable modes



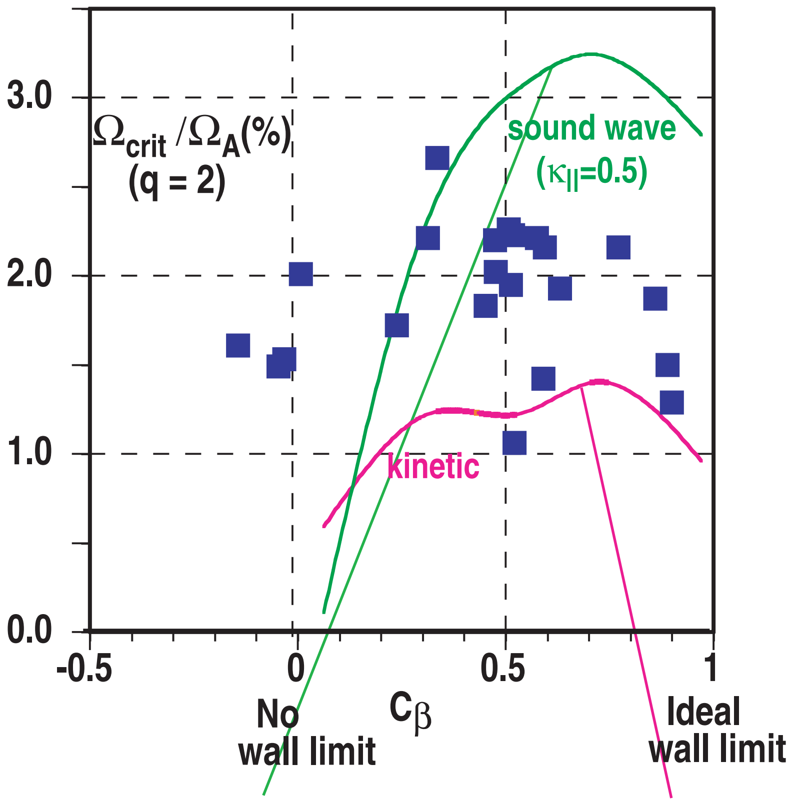
Prager OV / 4-2

Drake EX/P 2-20

WHAT DISSIPATION MECHANISMS PROMOTE STABILITY?

Comparisons with MARS calculations:

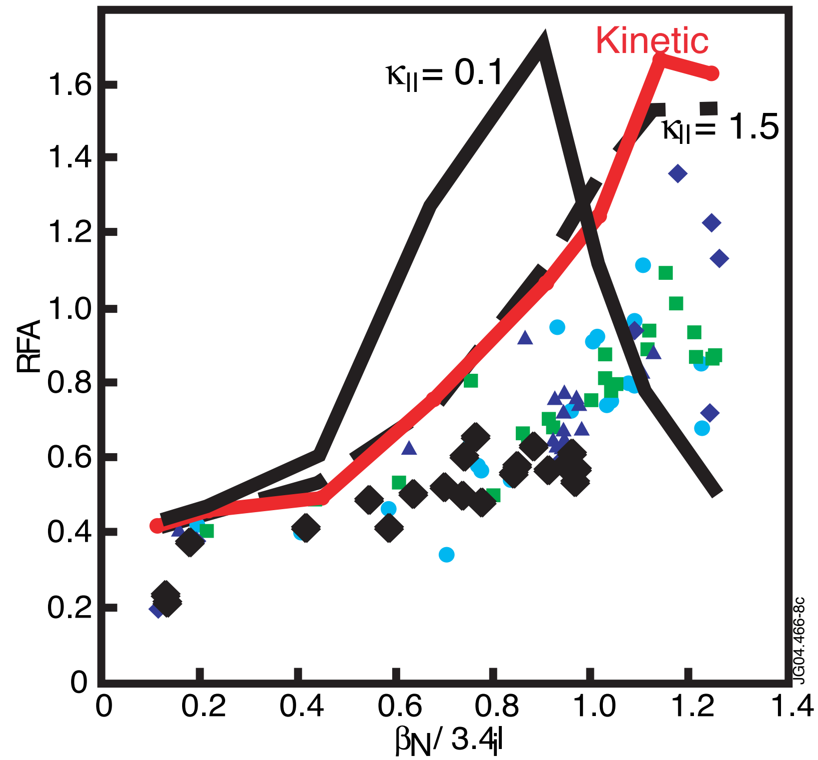
- Critical rotation velocity



Soundwave damping overestimates the critical rotation

Kinetic damping underestimates the critical rotation

- Resonant Field Amplification



DIII-D

Okabayashi EX/3-1Ra

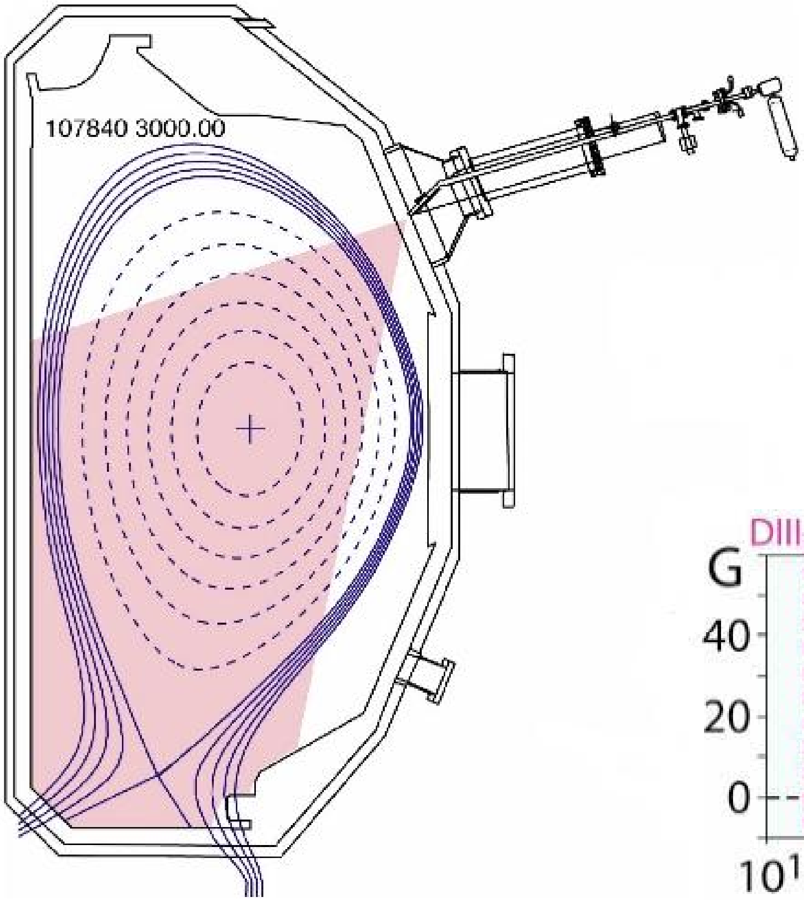
Reimerdes EX/3-1Rb

JET

Hender EX/P 2-22

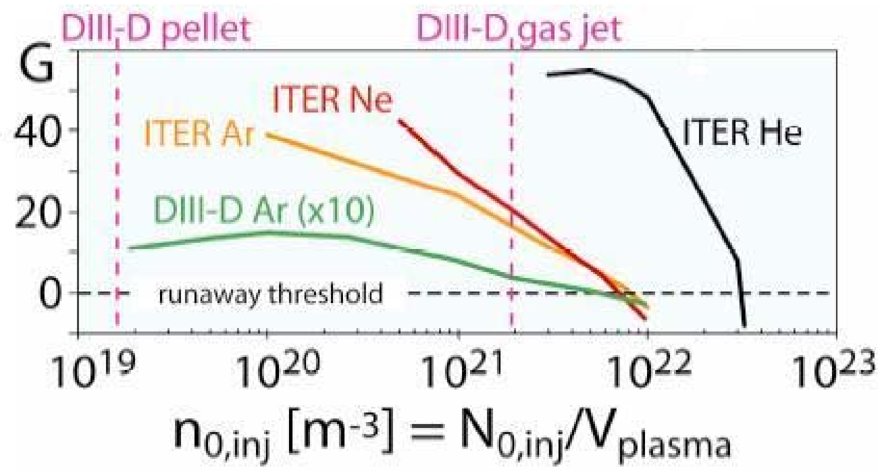
Other papers: Liu TH/2-1 and Strauss TH/2-2

Successful Disruption Mitigation by Massive Gas Injection.



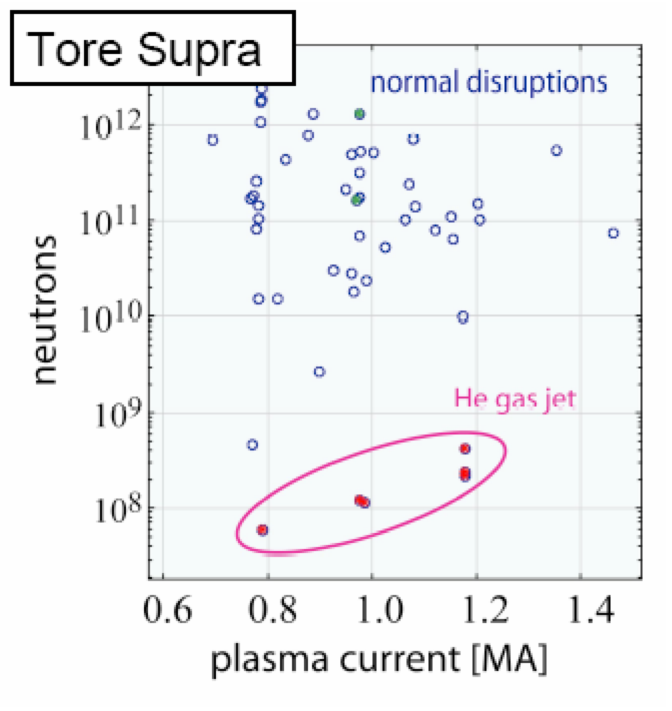
Runaway avalanche suppressed with sufficient electron injection.

Machine	Gas	$\frac{N_e}{V_{plasma}}$ [/m³]	$\frac{N_{0,inj}}{V_{plasma}}$ [/m³]
DIII-D	Ne,Ar	3e19	2e21
Tore Supra	He	3e19	3e21
JT-60U	Ar,Kr, Xe,H_2	1e19	6e19

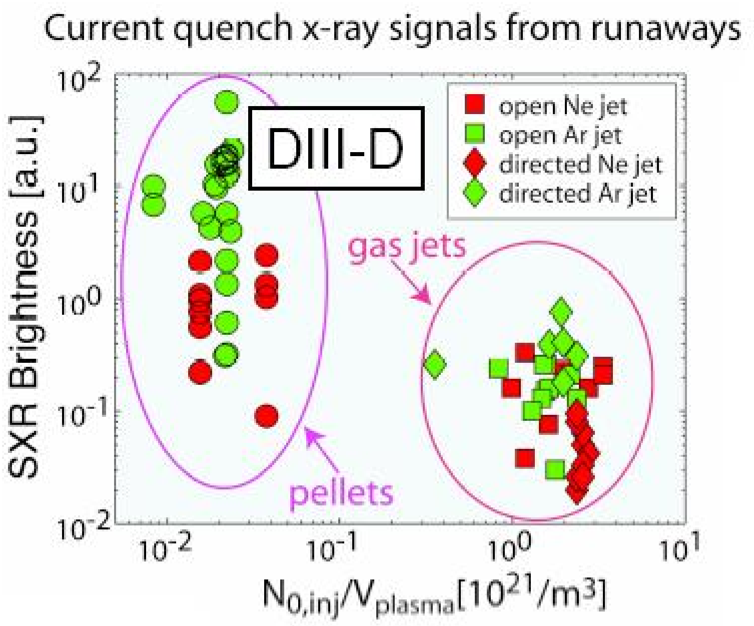


Runaways Tremendously Suppressed.

He Jet, EX/10-6Rc Tore-Supra

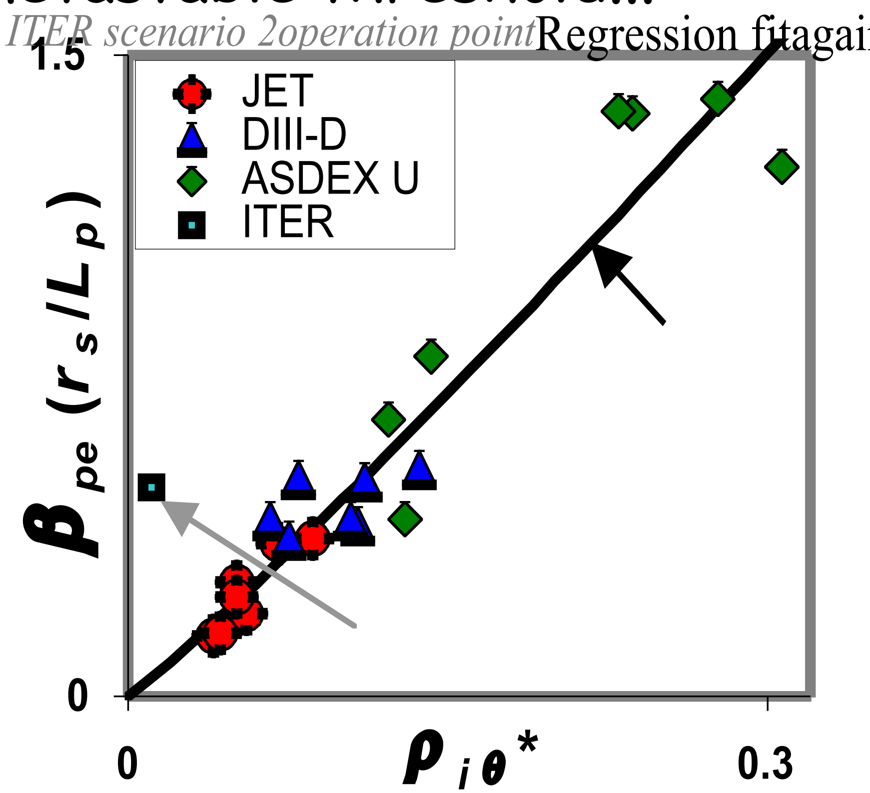


Gas Jets Better Than Pellets.
EX/10-6a DIII-D Hollmann



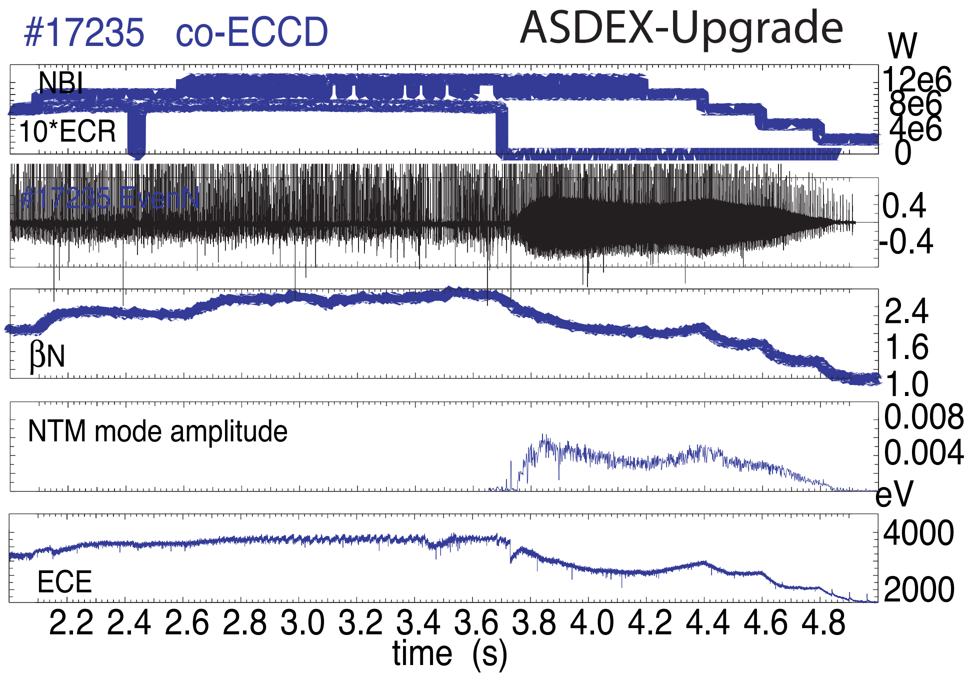
How do the ρ* scalings do?

Pretty good in terms of underlying NTM physics and metastable threshold...

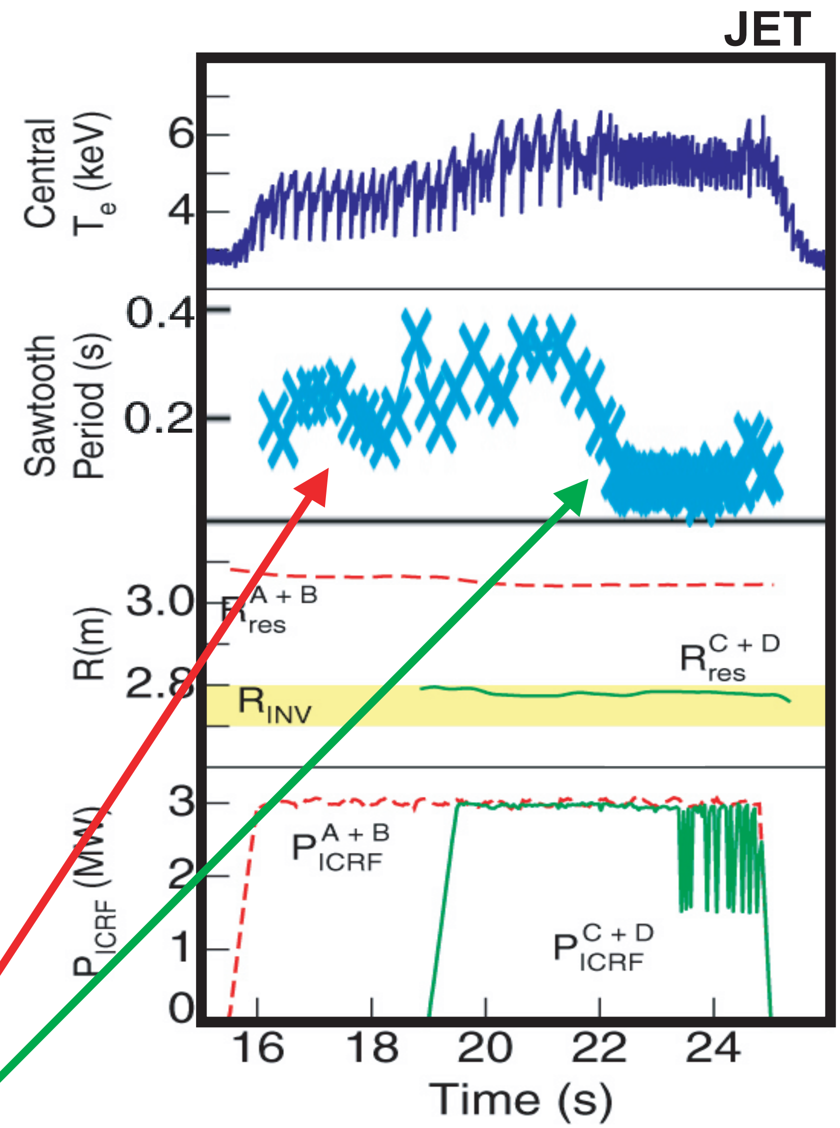


- power ramp-down experiments measure **β** at which 3/2 NTM self-stabilises
- **ITER baseline operation point deeply into metastable region**
  - small triggers can excite mode
  - mode removal requires driving island down to small sizes

SAWTOOTH CONTROL PREVENTS SEEDING OF NTMS



Maraschek EX / 7-2



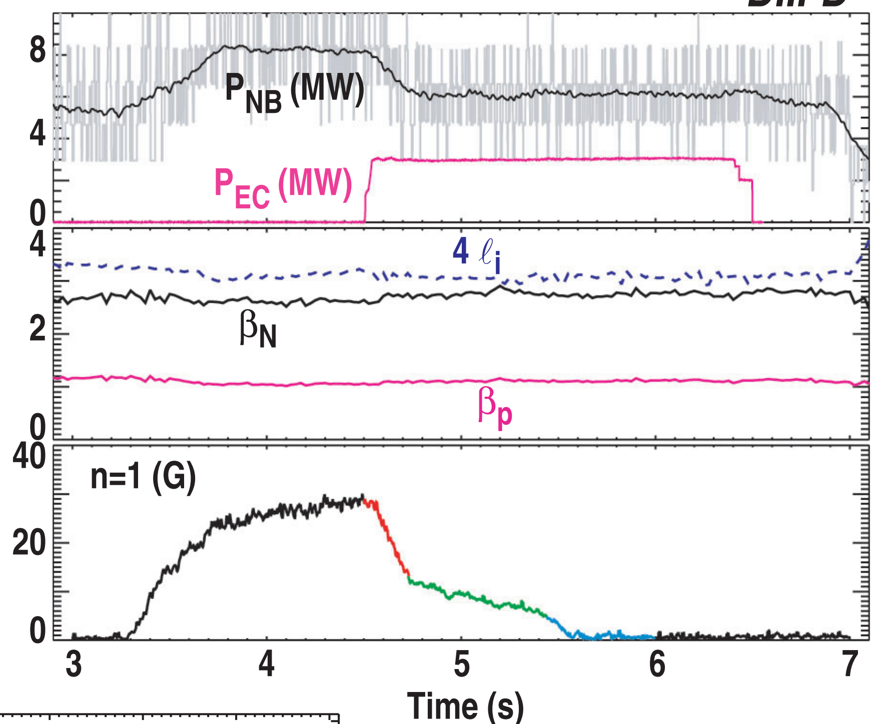
Destabilisation of fast particle stabilised sawteeth now achieved:

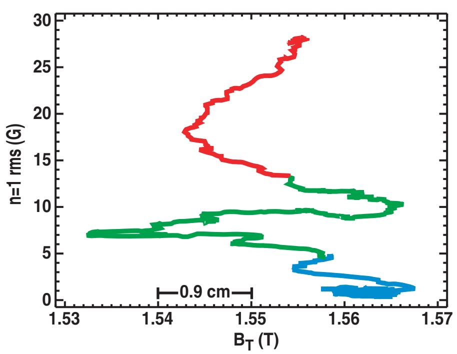
- core ICRH stabilises sawteeth
- ICCD destabilises as inversion radius is approached

Buttery EX / 7-1

2/1 TEARING MODE IS COMPLETELY SUPPRESSED BY ECCD

2/1 mode suppressed in hybrid discharge with β_N well above ITER baseline scenario

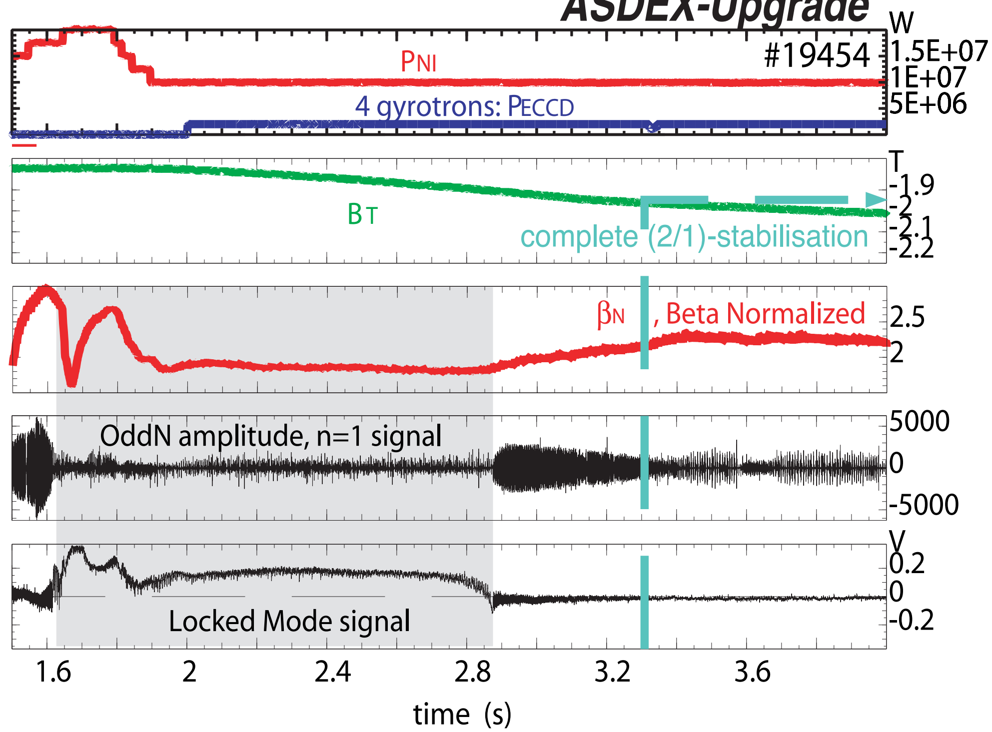




"Target lock" algorithm uses small, rapid variations in B_T to optimize suppression

Petty EX / 7-3

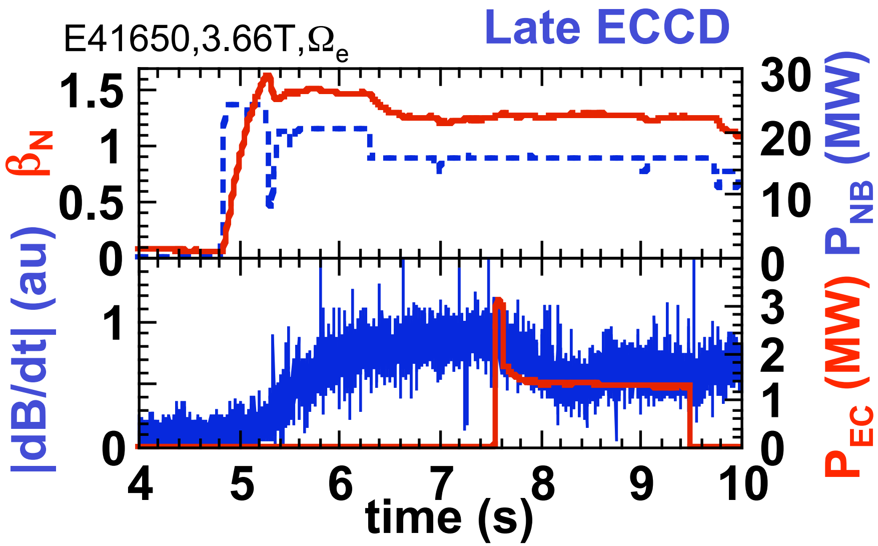
The (2/1)-NTM is preceded by a phase (grey shaded) where the mode is locked to the vacuum vessel

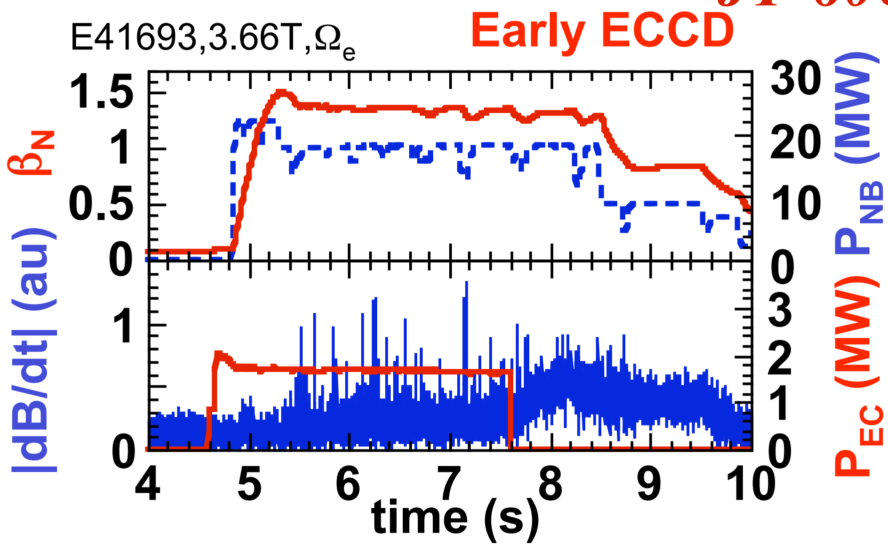


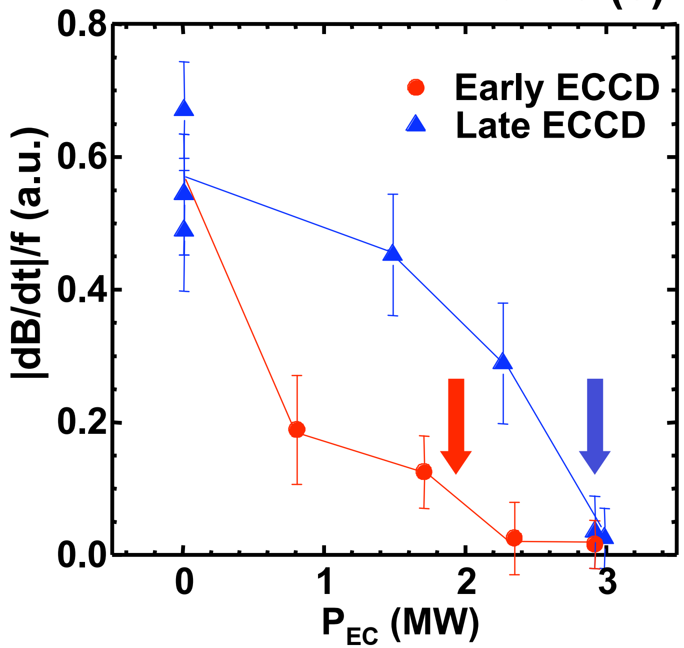
Maraschek EX / 7-2

Early ECCD is more effective for an NTM suppression, even at high β_N

JT-60U



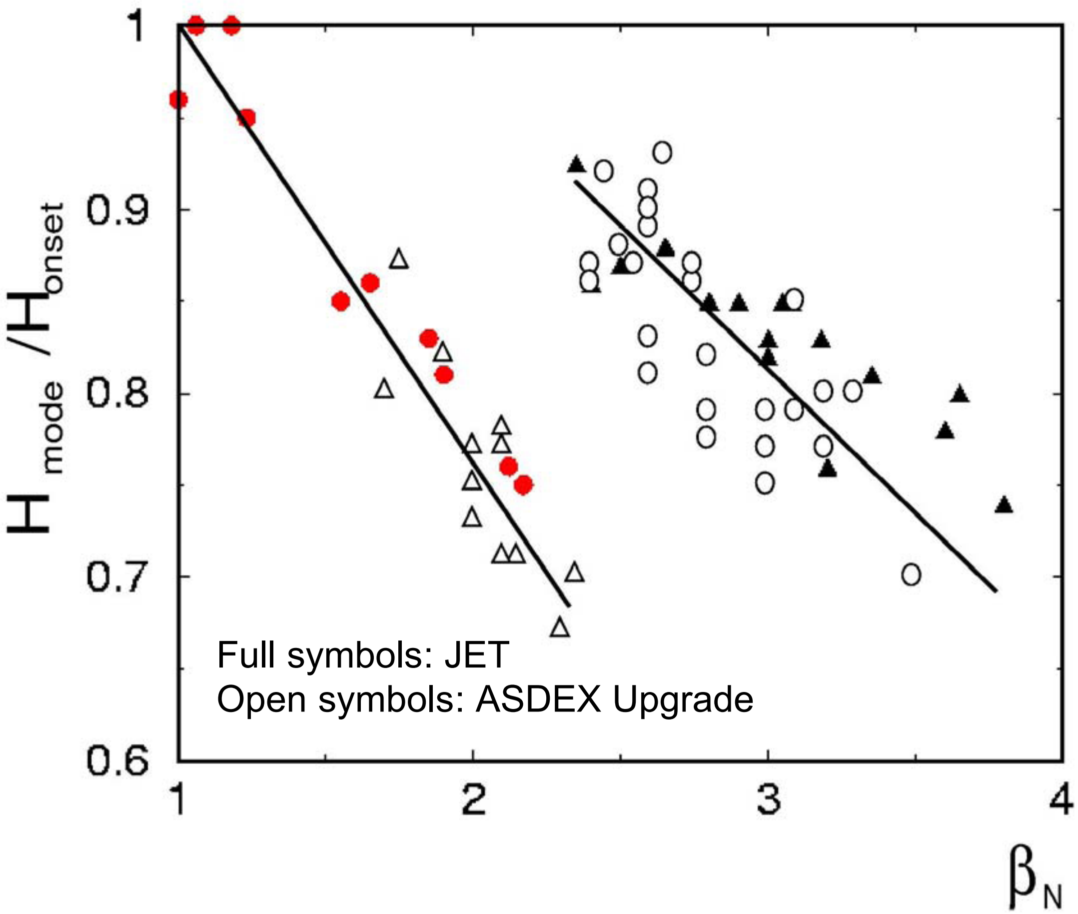


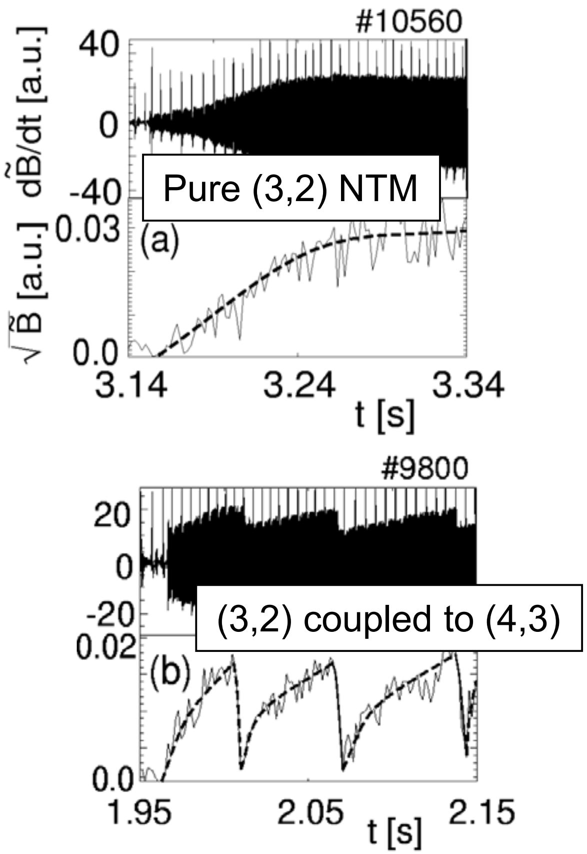


- **Early ECCD is more effective to suppress NTM:**
  - island size (~|dB/dt|/f) quickly suppressed
  - less power for full stabilization
  - calculated necessary power for full suppression based on mod. Rutherford eq. agrees well with the experiments (arrows).

K. Nagasaki (EX/10-3, Thu.)

(3,2) NTMs in FIR regime for β_N > 2.3



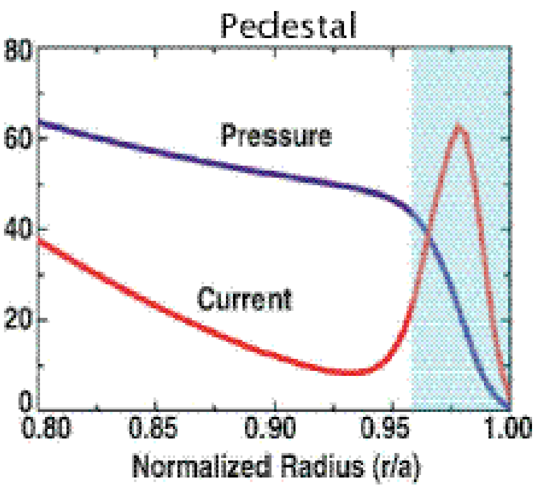


FIR regime similar in dimensionless parameters (ASDEX Upgrade and JET)

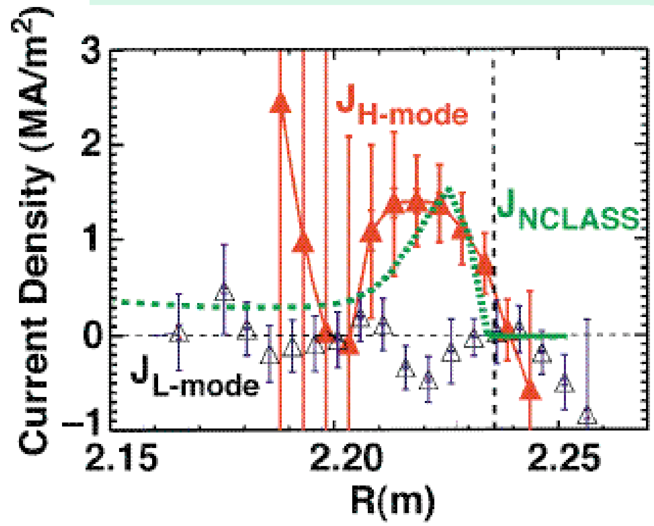
Active stabilization on ITER only for (2,1) NTM needed?

Guenter	OV / 1-5
Maraschek	EX / 7-2

PEELING-BALLOONING MODEL OF ELMS CONVERGING



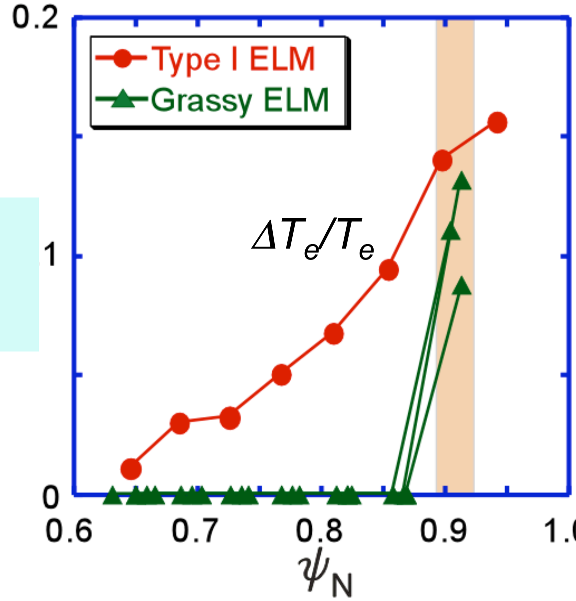
EX/2-5Rb DIII-D Fenstermacher



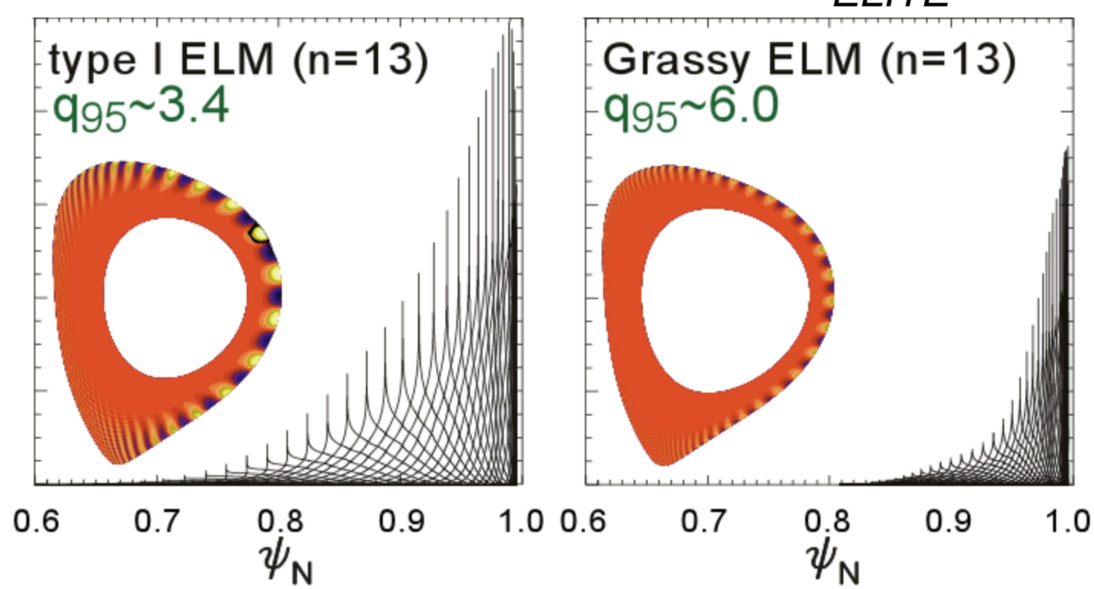
EX-P/1-4
JET
Stober

EX-P/3-4
AUG
Horton

EX/2-1
JT-60U
Oyama

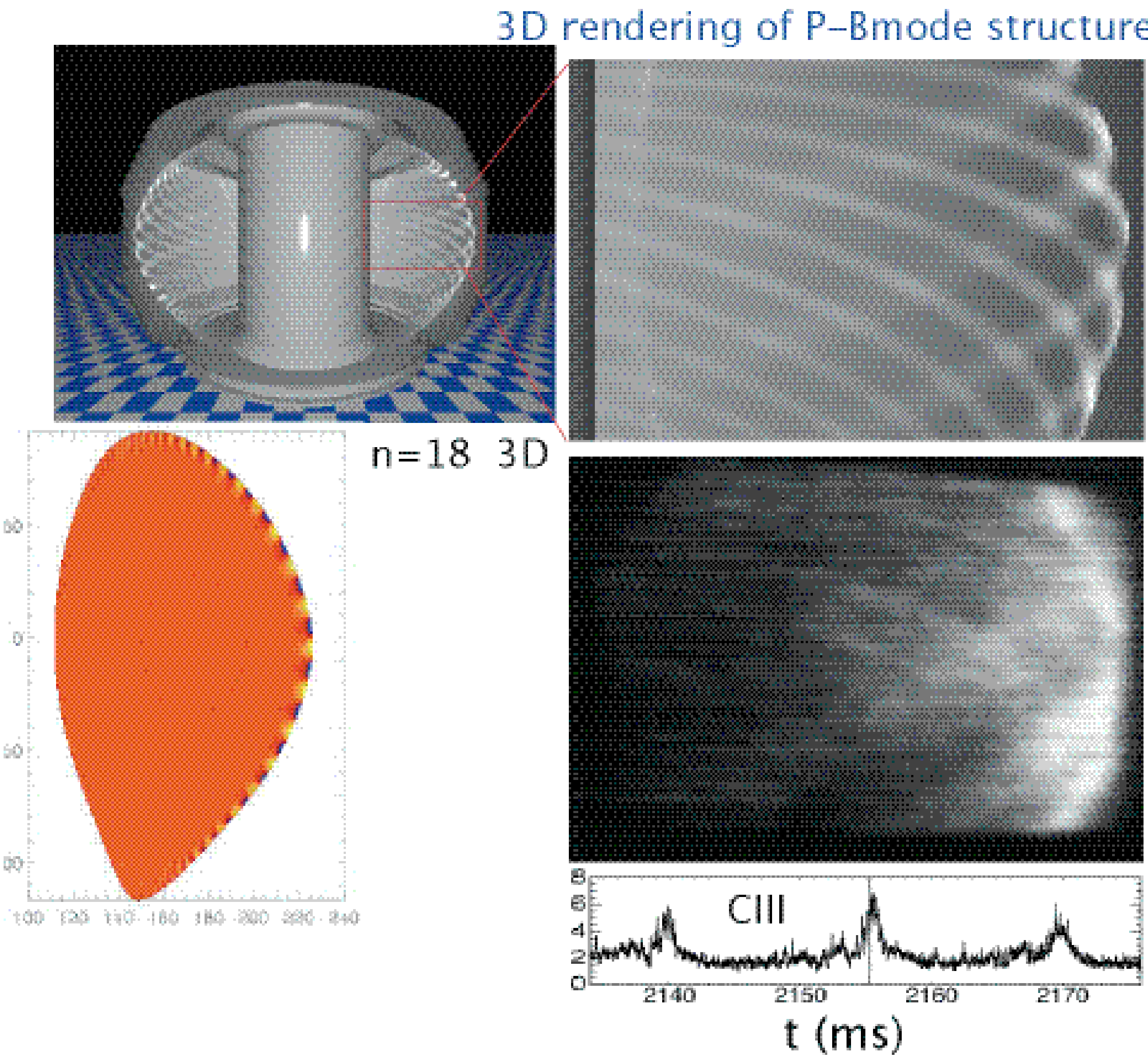


ELITE



FILAMENTARY STRUCTURE OF ELMS – MAJOR SUBJECT

EX/2-5Rb DIII-D Fenstermacher

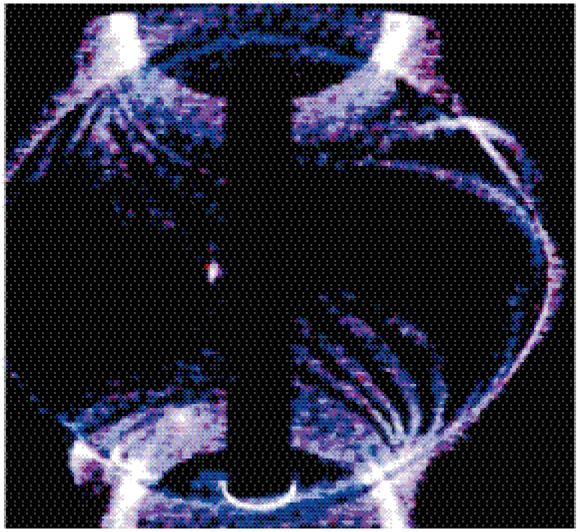


Most unstable modes from ELITE linear P-B stability analysis are 16 ≤ n ≤ 24

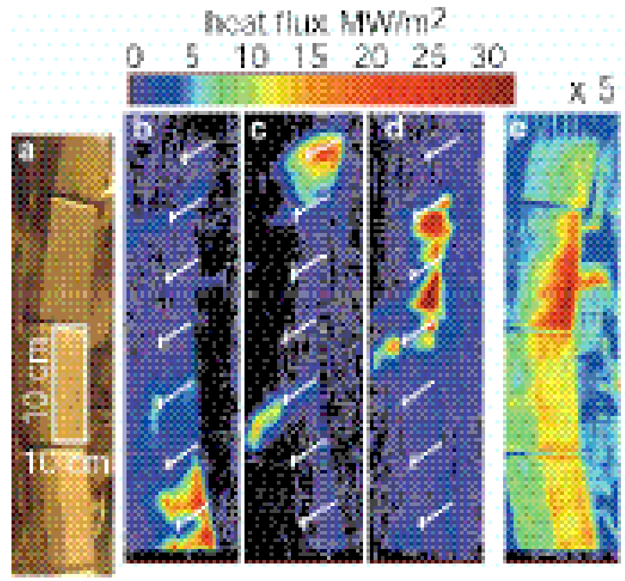
CIII emission structure during ELM suggests n ~17

FILAMENTARY STRUCTURE SEEN IN MANY MACHINES

EX/2-3 MAST Kirk

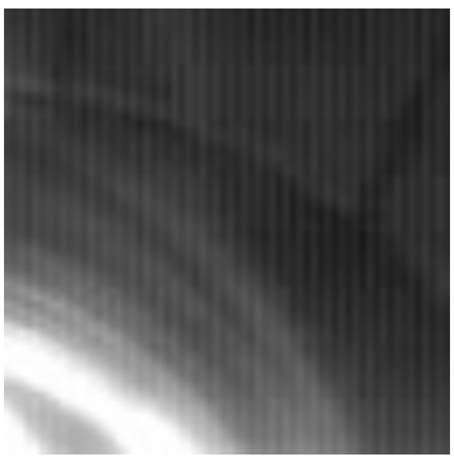


EX/2-4Rb AUG Hermann



EX/2-6
AUG
Lang

EX/2-2
NSTX
Maingi



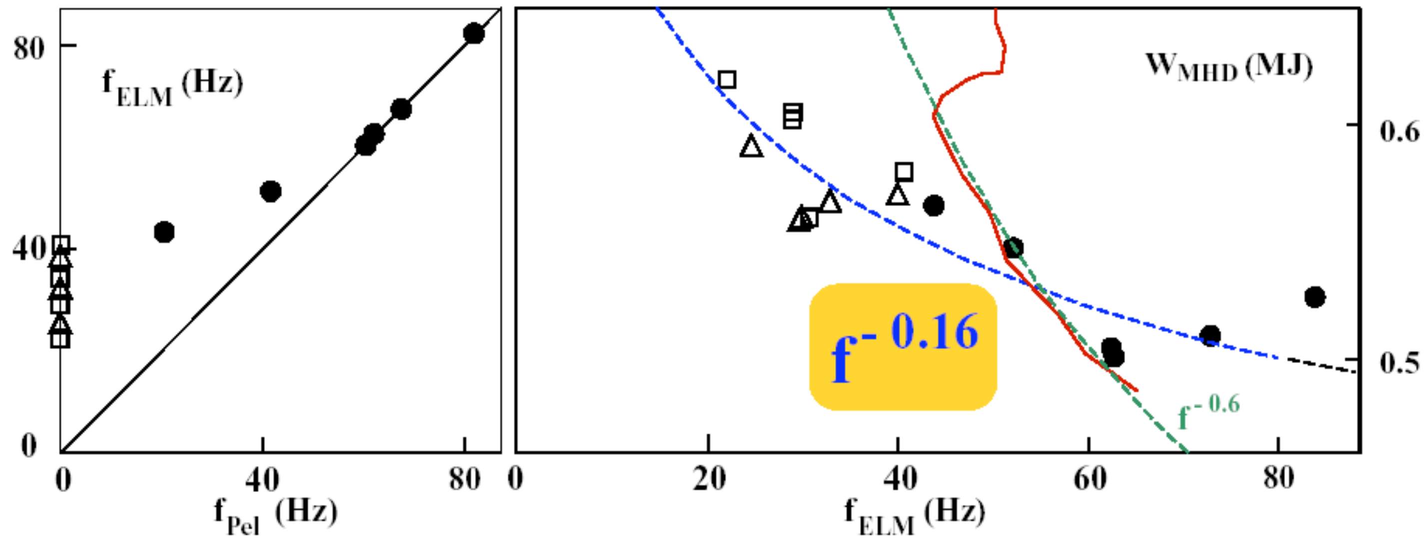
Detailed Filamentary Nature of ELMs
In EX/2-4Ra JET Fundamenski

Strike Point Jump
EX/P1-3 JET Solano

ELM CONTROL BY PELLET PACE MAKING

Replace linearly unstable peeling/ballooning mode by local trigger perturbation

OV/1-5
AUG
Guenter



Pace making

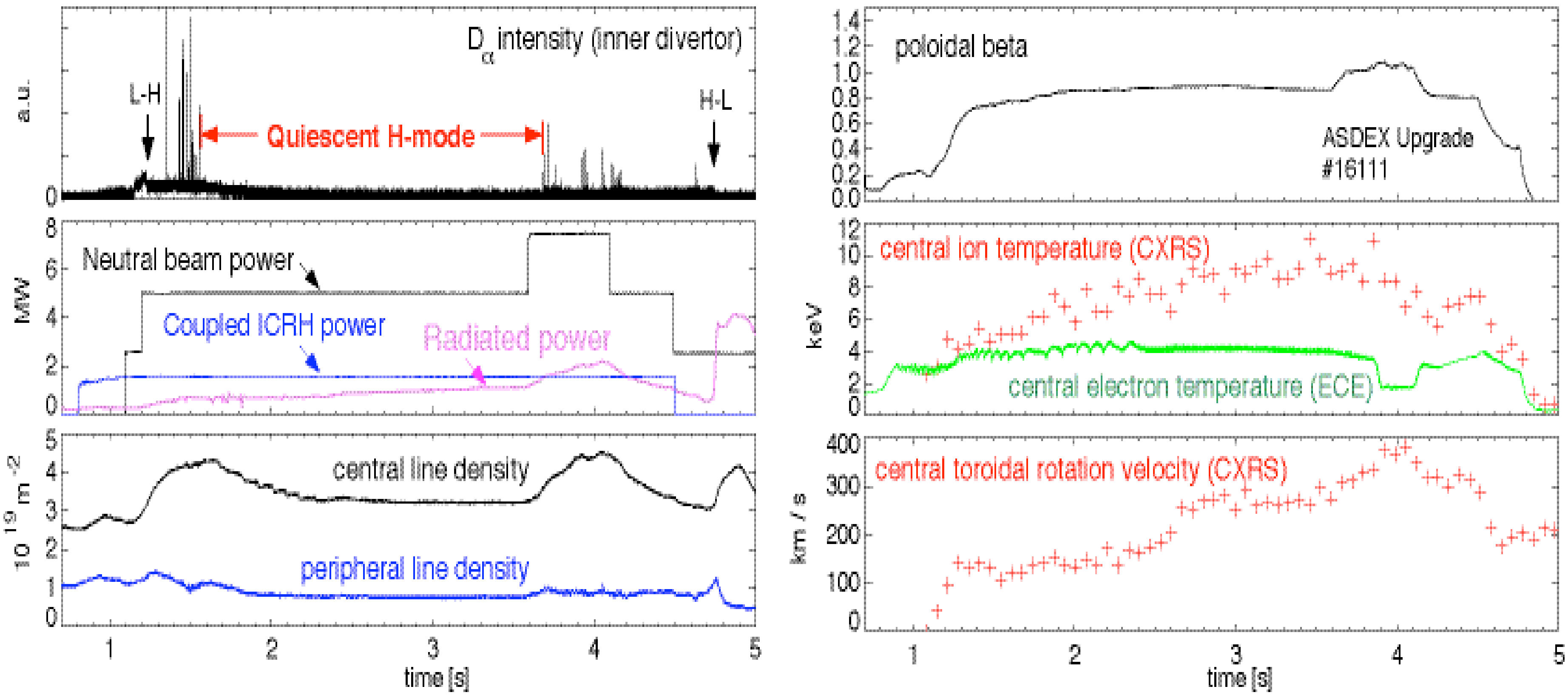
Performance

EX/2-6
AUG
Lang

- only minor confinement degradation with increased ELM frequency compared to, e.g., gas puffing (pedestal temperature reduced!)
- energy loss per ELM for pellet triggered ELMs as for “natural” ELMs
- successful ELM control also by small wobbling

QH-MODE IN ASDEX UPGRADE

EX/1-4 AUG Suttrop

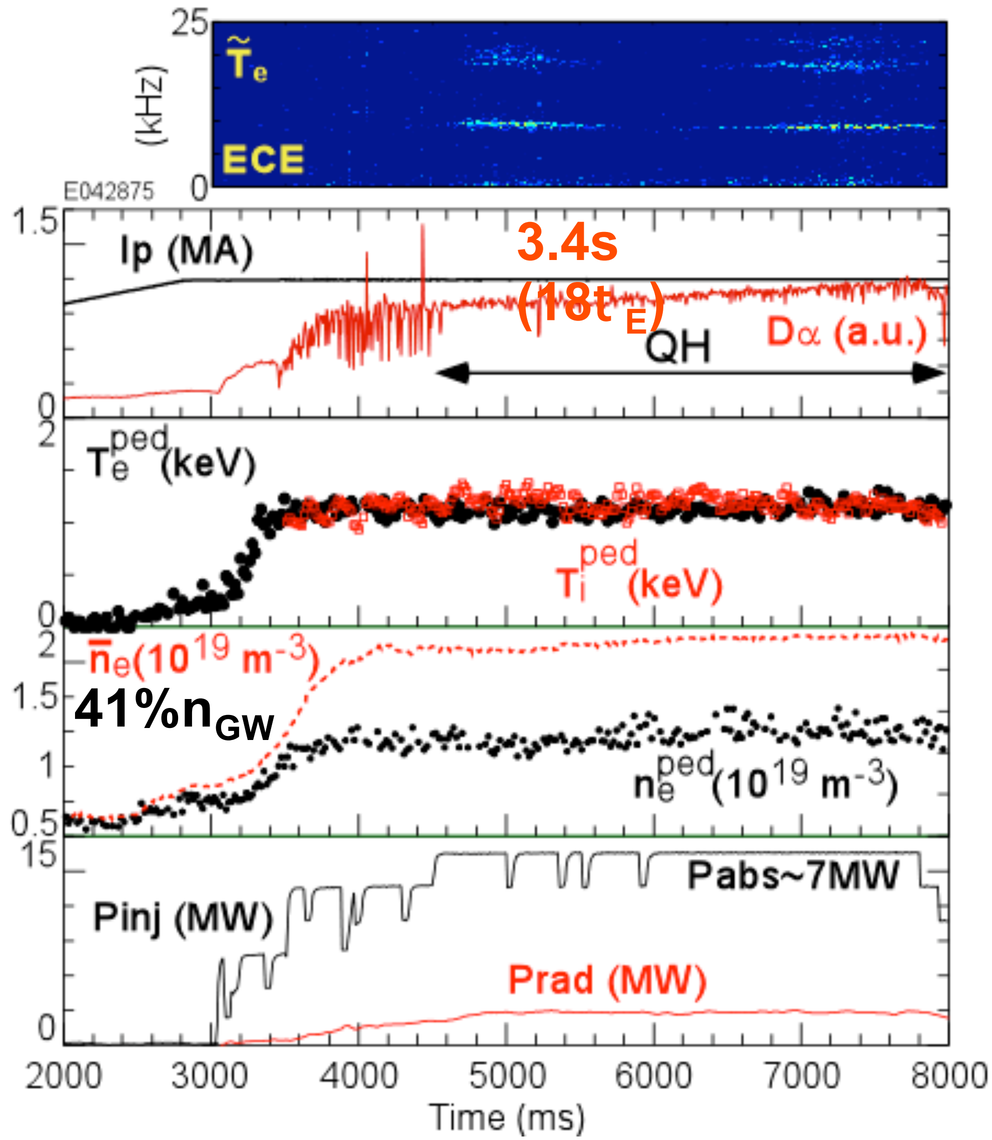


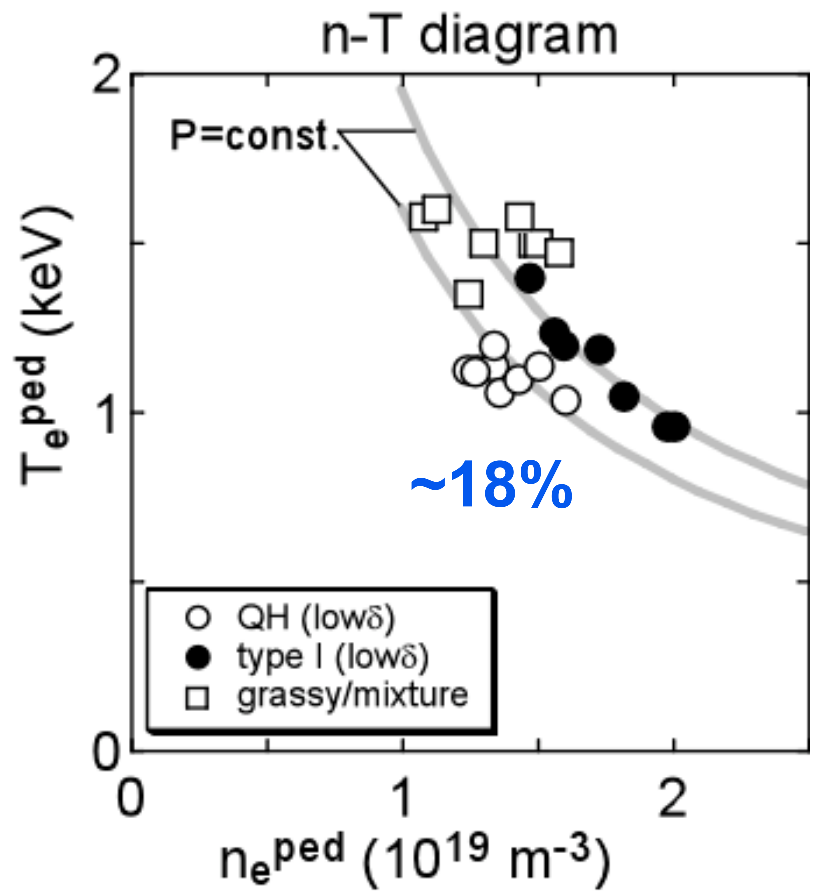
- **Large E_R in the barrier, 2 × normal H-mode**
- **Energetic particle effects near the barrier**
- **EHO/HFO necessary features**

QH-MODE IN JT-60U

EX/2-1 JT-60U Oyama

- Pedestal parameters almost constant during QH phase





T_i^{ped} also smaller in QH phase

ELM AMPLITUDE AND FREQUENCY CAN BE CHANGED BY TOROIDAL ROTATION

JT-60U

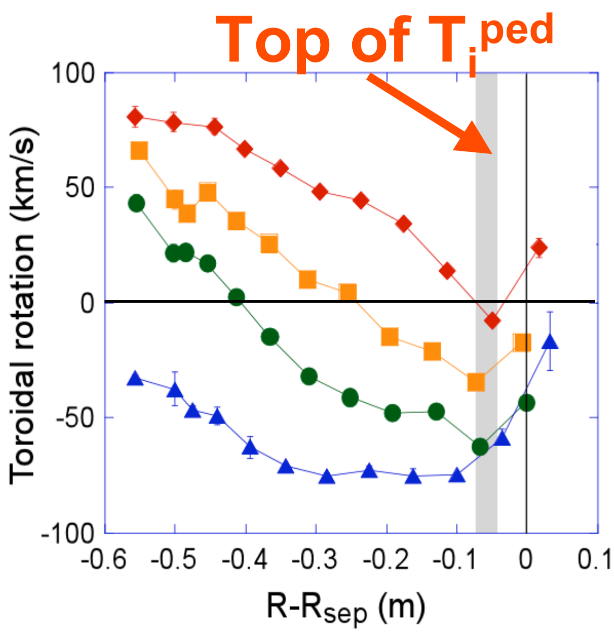
- Larger counter rotation leads to smaller ELM and higher f_{ELM}.

EX/2-1 JT-60U Oyama

- New parameter for access to grassy ELM regime.

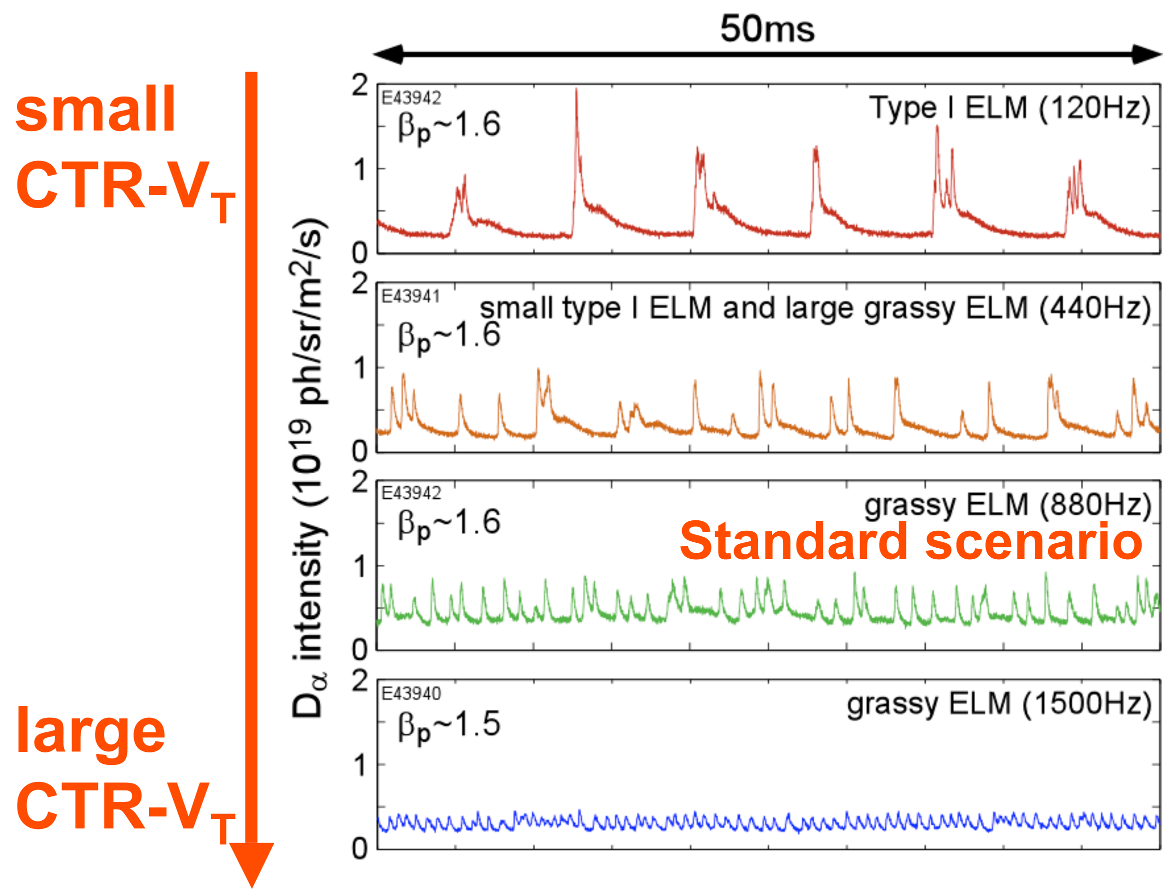
  Absolute value? or Sign?

- No edge fluctuations were observed even in larger counter rotation phase.



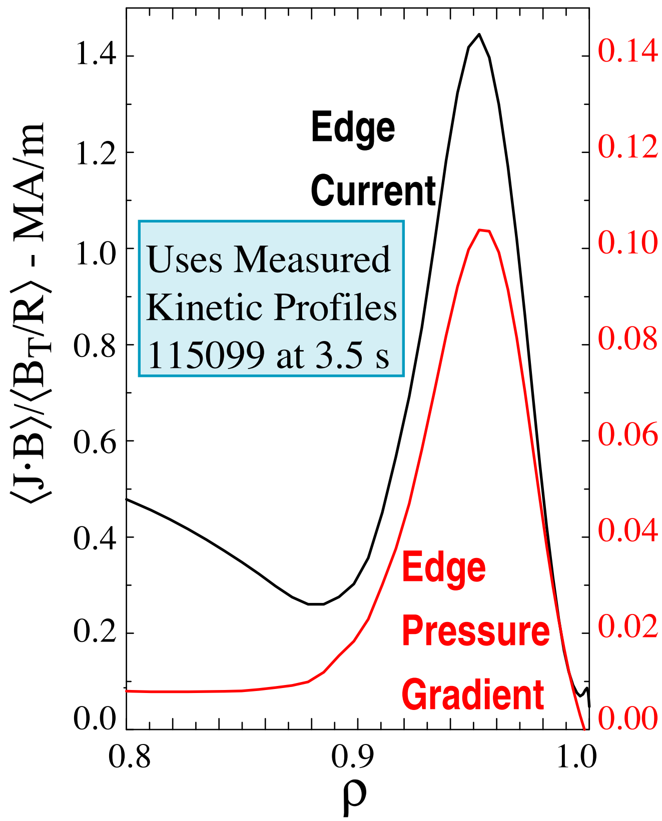
Toroidal rotation profile

(q_{95}~4.9, d~0.6)

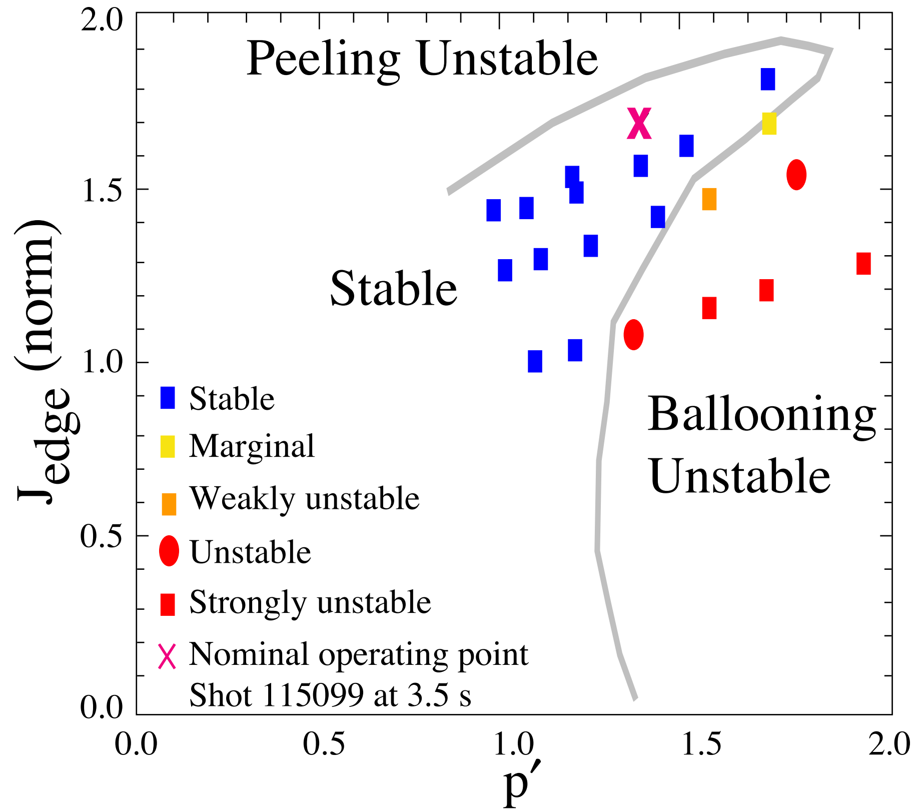


ELITE STABILITY MODELING: QH MODE IS MARGINALLY STABLE TO CURRENT DRIVEN PEELING/BALLOONING MODES

Edge Current (from NCLASS) and Pressure Profiles in CORSICA equilibrium

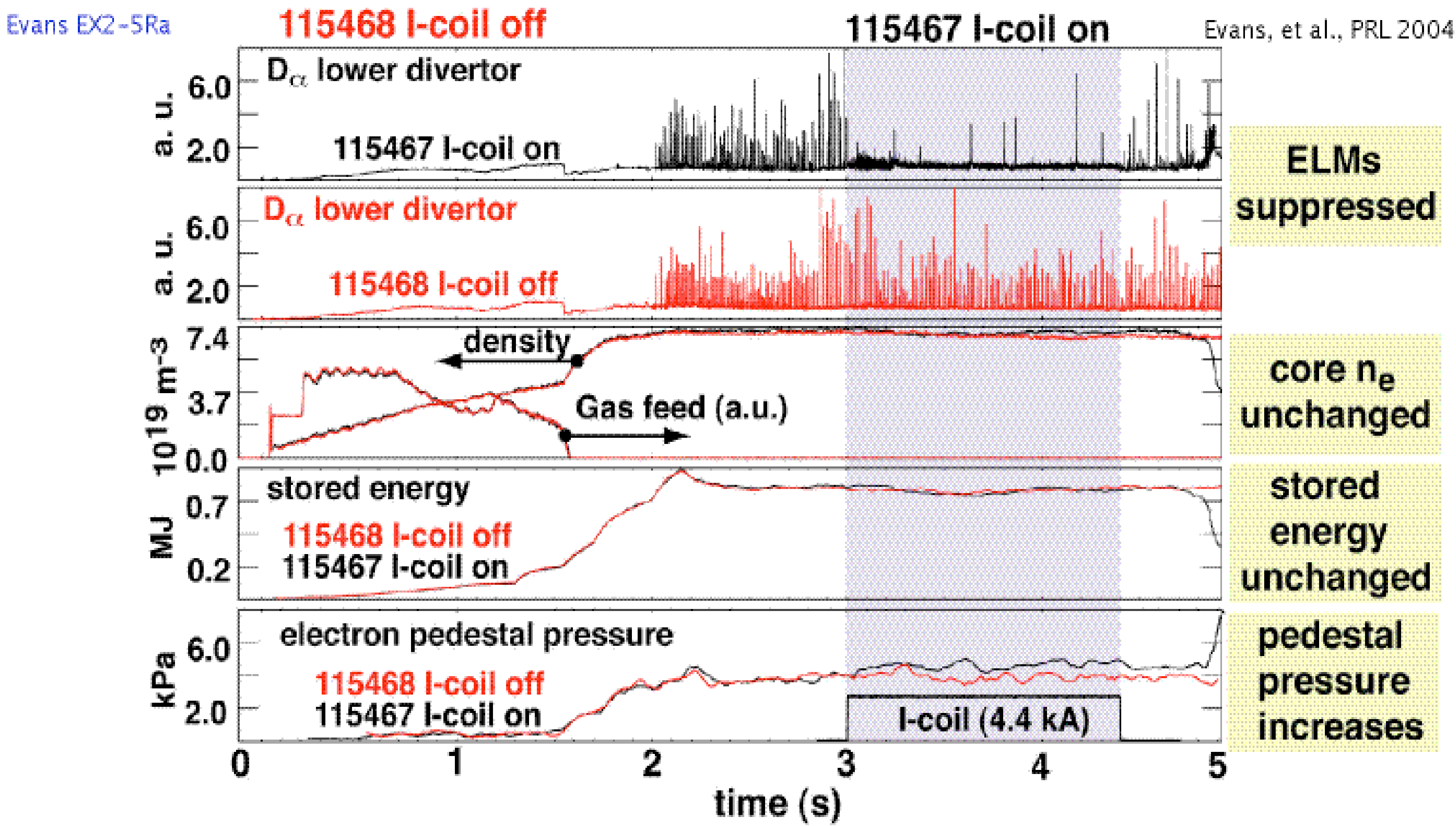


ELITE Stability Diagram from the experimental case, x, and perturbed equilibria, ■



Upward I_P ramps during QH operation induce ELMS, supporting the ELITE result of marginal stability to current driven modes.

EDGE FIELD PERTURBATION CAN SUPPRESS ELMS WITHOUT DEGRADING CONFINEMENT

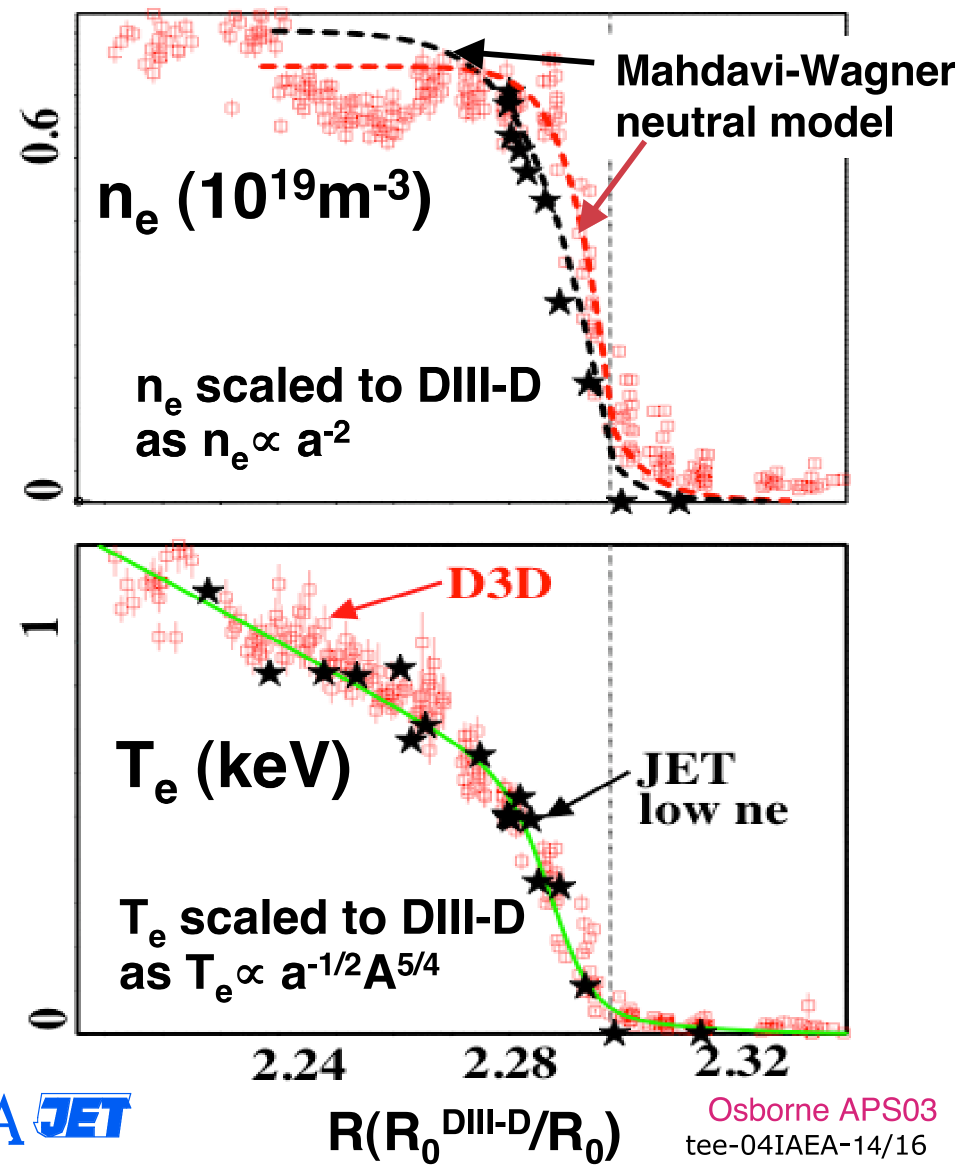


- Several isolated ELM-like events remain
- ELMs return after I-coil pulse turns off

DIII-D/JET pedestal similarity experiments show importance of neutral penetration

Fenstermacher
EX2-5Rb

- **Matched shapes and (β, ν_*, ρ_*, q) at top of pedestal**
- **Neutral penetration physics dominates in setting the density width**
  - **Mahdavi-Wagner model reproduces differences in DIII-D vs JET profiles**
- **Plasma physics dominates in setting the transport barrier**
  - **T_e width $\propto$ a**



EX/2-5Rb DIII-D Fenstermacher.
See also EX/P3-4 AUG Horton

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

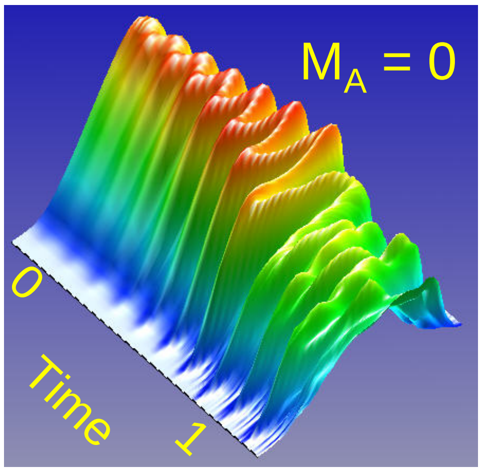
EFDA JET

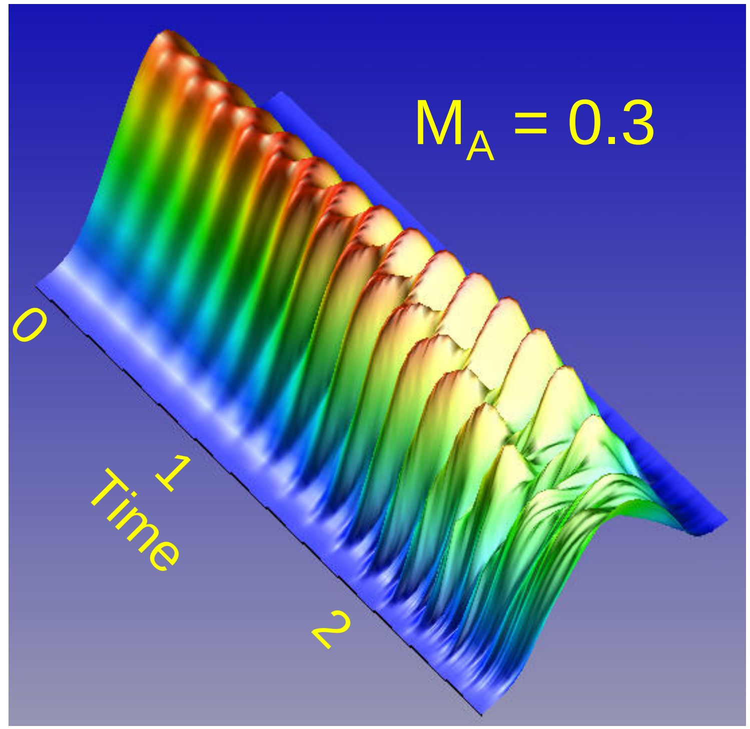
Osborne APS03
tee-04IAEA-14/16

M3D: Sheared-flow reduces growth rate by factor of 2-3

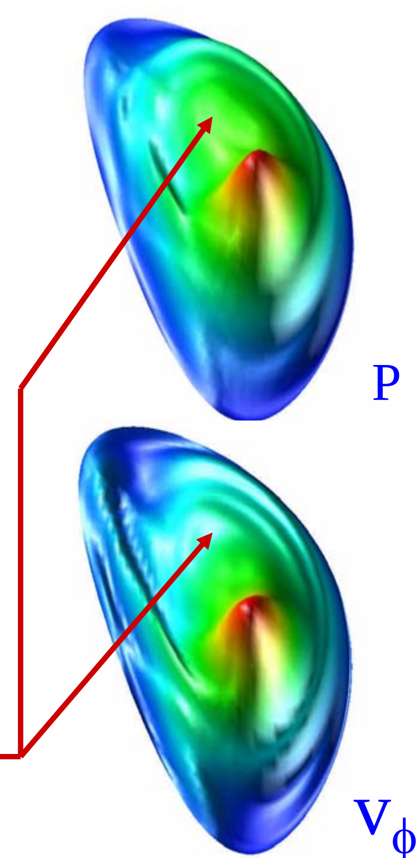
- **Possible because $\gamma_{shear} \sim \Omega_{rotation}$ can be of > γ_{linear}**

Simulated SXR signals



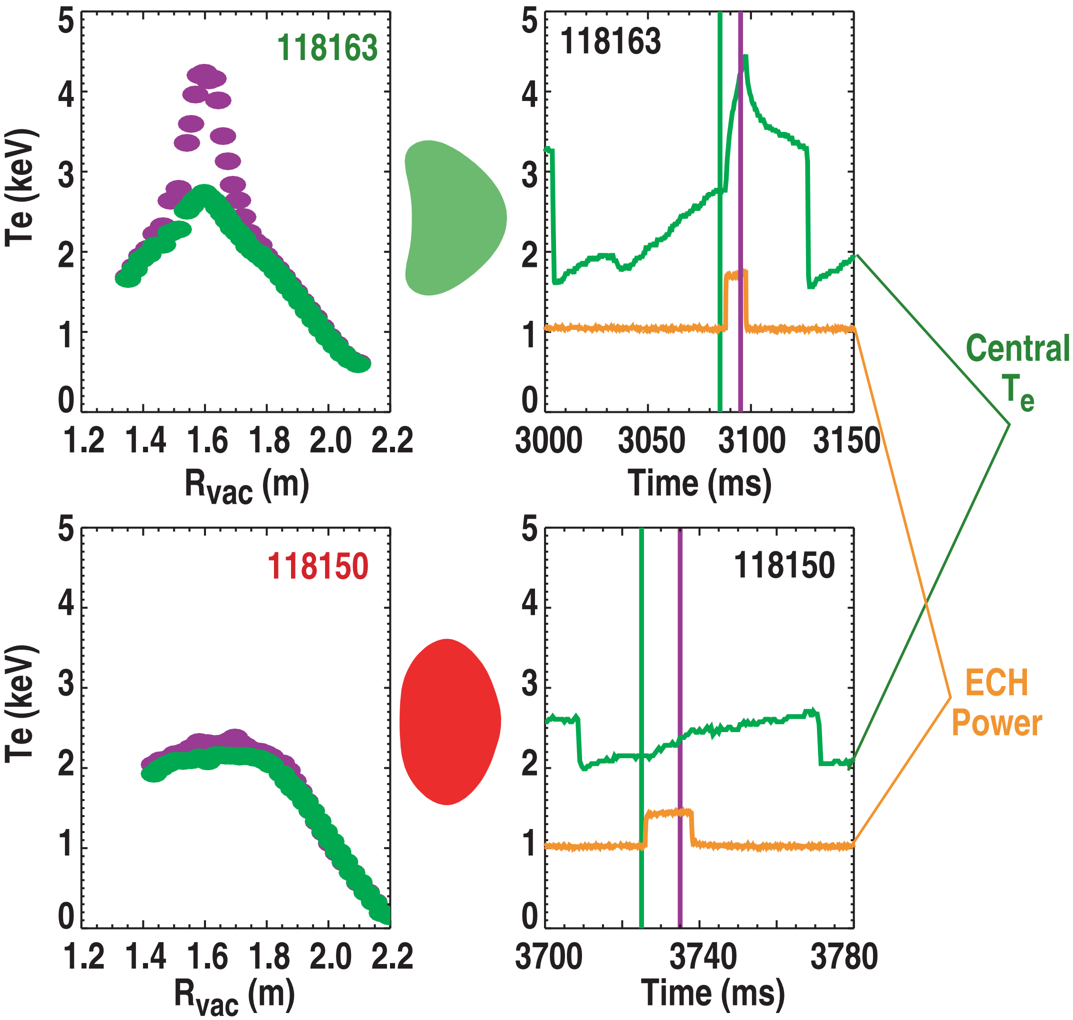


M3D simulations



- In experiment, the NBI power is held roughly fixed
- In **M3D**, with a *fixed momentum source rate*, the v_ϕ and ***p*** profiles *flatten* inside the island, **reconnection *still* occurs (saturated state rare)**

PLASMAS THAT VIOLATE THE MERCIER CRITERION DO NOT SUPPORT AN ELECTRON PRESSURE GRADIENT



Indented Plasmas:

- Mercier limit occurs at q<1
- Local electron heating results in strongly increased gradient

Oval Plasmas:

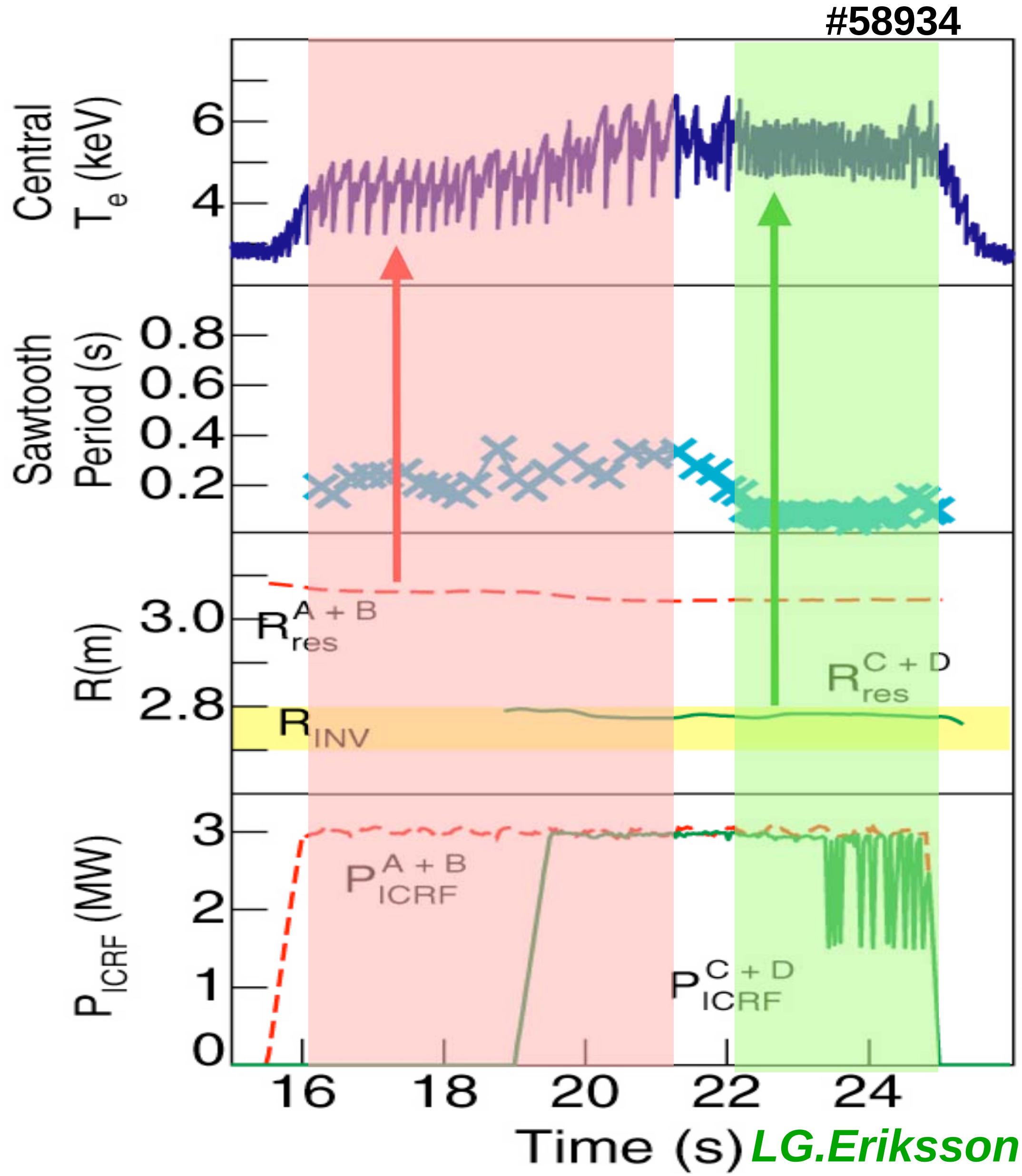
- Mercier limit occurs at q>1
- Local electron heating results in almost no change in gradient

Lazarus – Fri. AM Poster

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

248-04/TCL/rs

'Monster' sawtooth control



core +90º phasing ICRH to make fast particles and large sawteeth (period up to 0.4s)

q=1 -90º phasing ICRH for current drive sawtooth destabilisation

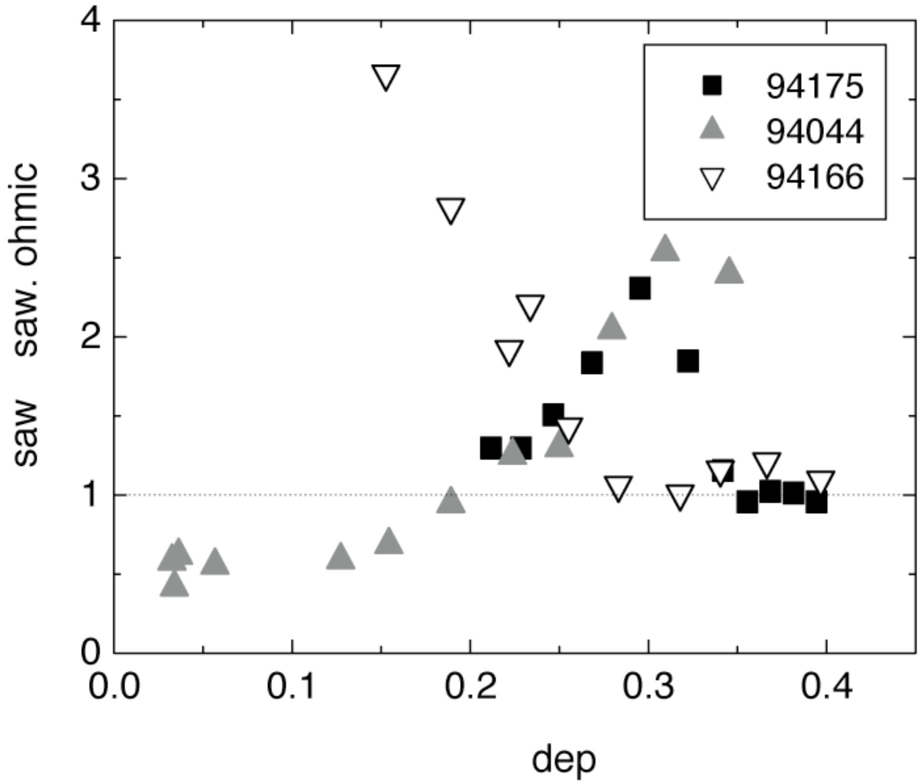
Essential technique for ITER to control fast alphas stabilised sawteeth

R.Buttery, EX/7-1

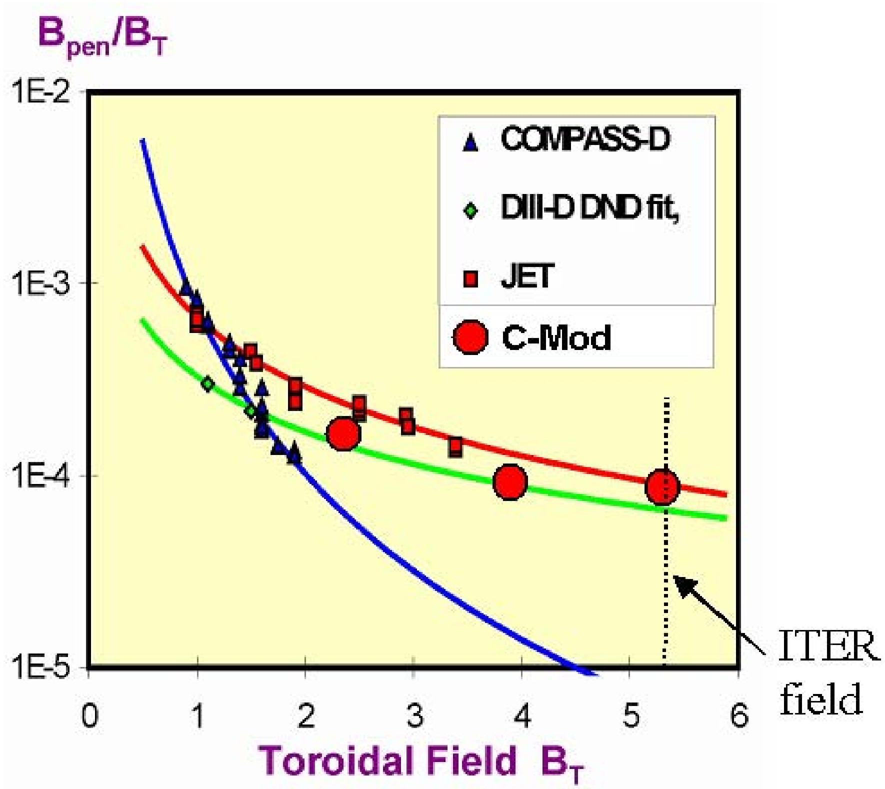
LG.Eriksson et al PRL92 (2004)235004

EC Effects on Sawtooth Period

EX-P/5-16 TEXTOR Westerhof



LOCKED MODE THRESHOLD HAS WEAK SIZE SCALING

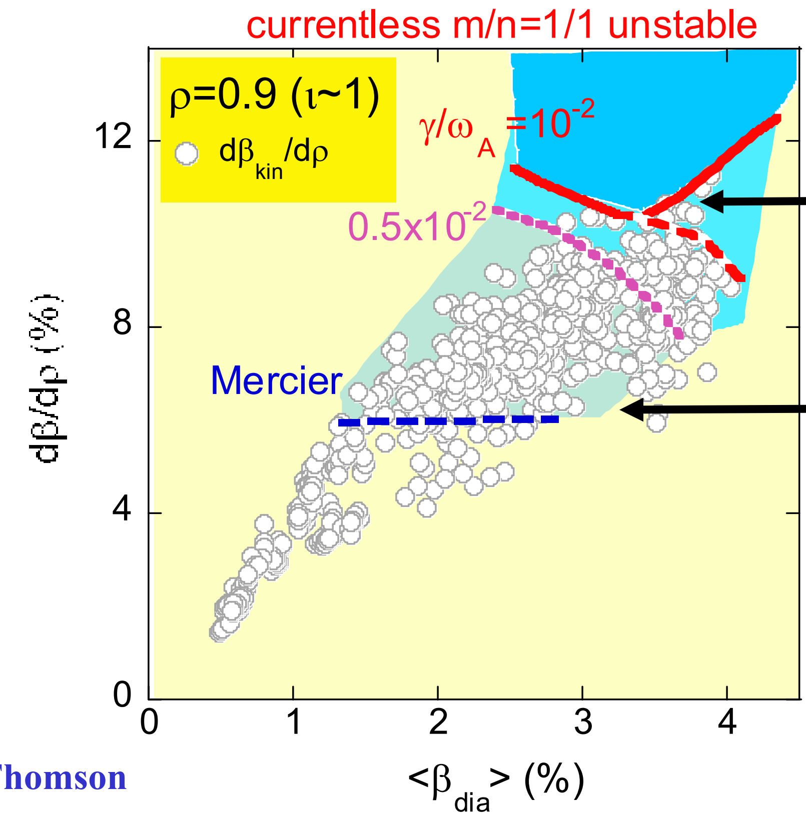


Hutchinson EX/P5-6

- Set of external non-axisymmetric control coils installed.
- Allow determination of intrinsic error field and mode locking threshold.
- Dimensionless identity experiments performed w/JET, DIII-D.
- Weak size scaling found.
- Locked modes should not be worse for ITER than for current machines
- Coils allowed suppression of locked modes, 2 MA operation.

Study on MHD stability limit of high beta plasma

Role and Function of Boundary



Achieved beta is close to the m/n=1/1 ideal mode limit

Achieved beta significantly exceeds the Mercier limit

γ=1.22

(γ=n/m·a_c/R=$\kappa\varepsilon$)

T_e(T_i): Thomson

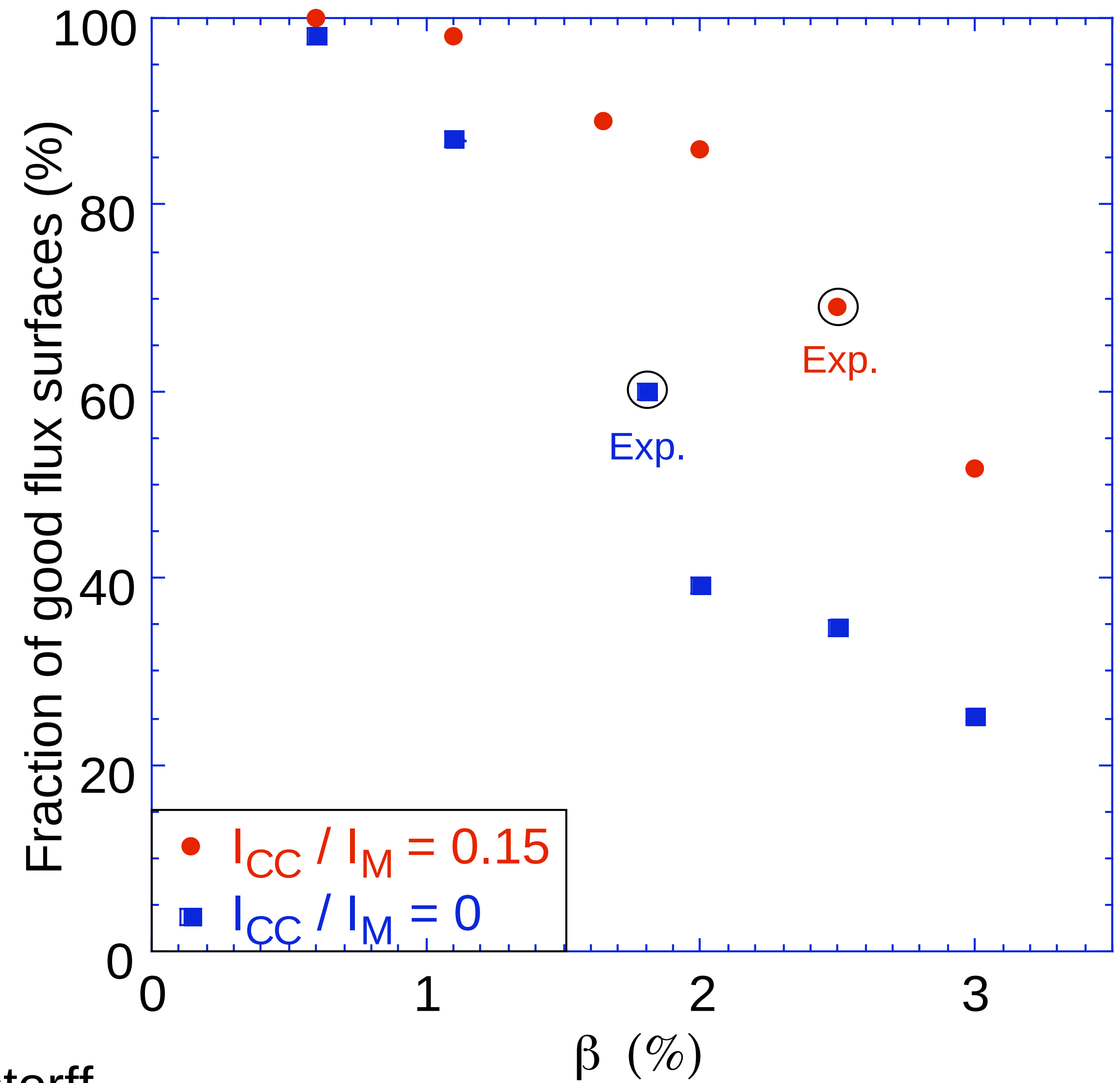
n_e:FIR

- β values achieved significantly exceeds the Mercier limit and increases up to m/n=1/1 ideal MHD limit

kinetic beta gradients at ρ=0.9 (ι/2π = 1) in <β>-dβ/dρ diagram.

Degradation of Equilibrium May set β Limit

- PIES equilibrium calculations indicate that fraction of good surfaces drops with β
- Drop occurs at higher β for higher I_{CC} / I_M
- Experimental b value correlates with loss of ~35% of minor radius to stochastic fields or islands
- Loss of flux surfaces to islands and stochastic regions should degrade confinement. May be mechanism causing variation of β.



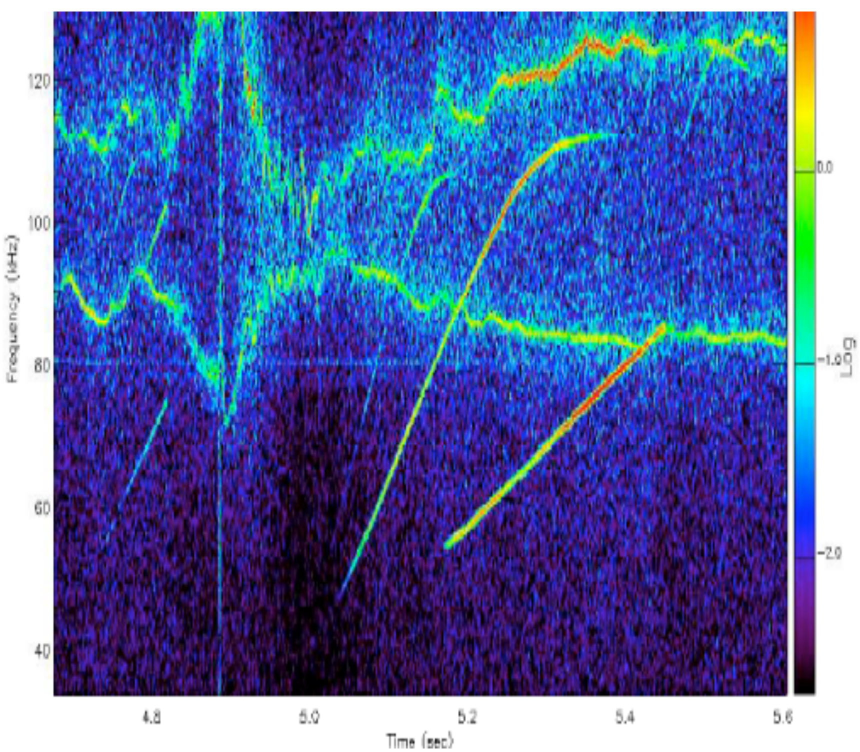
EX/3/4 W7-AS Zarnstorff

Other Stability Results

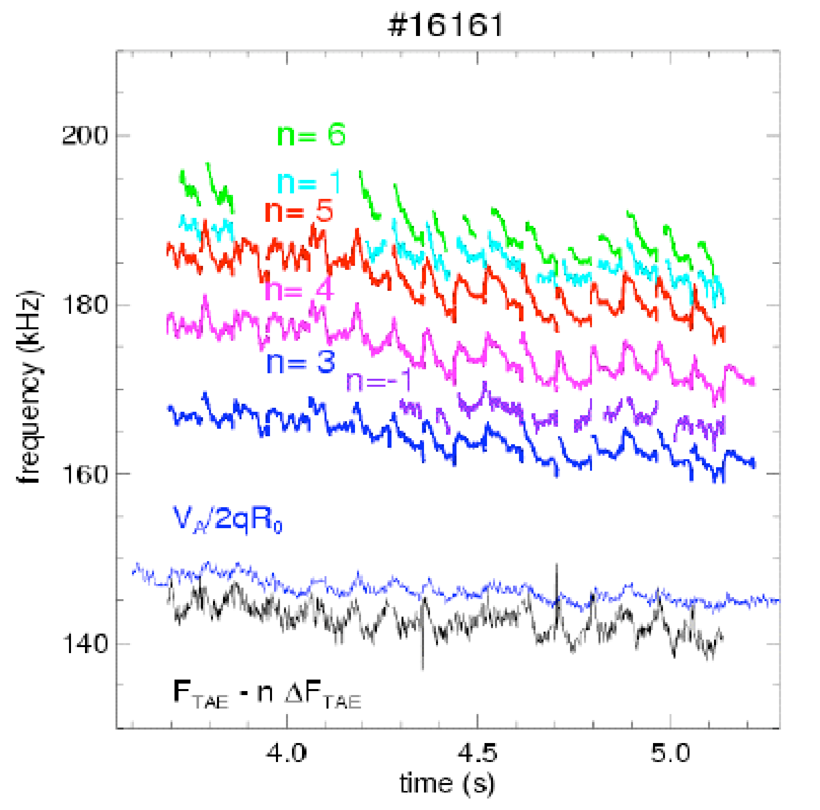
- EX-P/5-8 CT-6B Khorshid - Limiter Biasing Affects Rotation Which Affects MHD Stability
- EX-P/5-12 HL-1M Liu - Snake Perturbations Excited by Pellet Injection and During LHCD
- EX-P/9-6Rb HANBIT Jhang - Interchange Stability Window with Strong RF

ALFVEN EIGENMODES

Alfven cascades excited by ^{4}He ions in JET reversed-shear discharge
EX/5-2 Sharapov

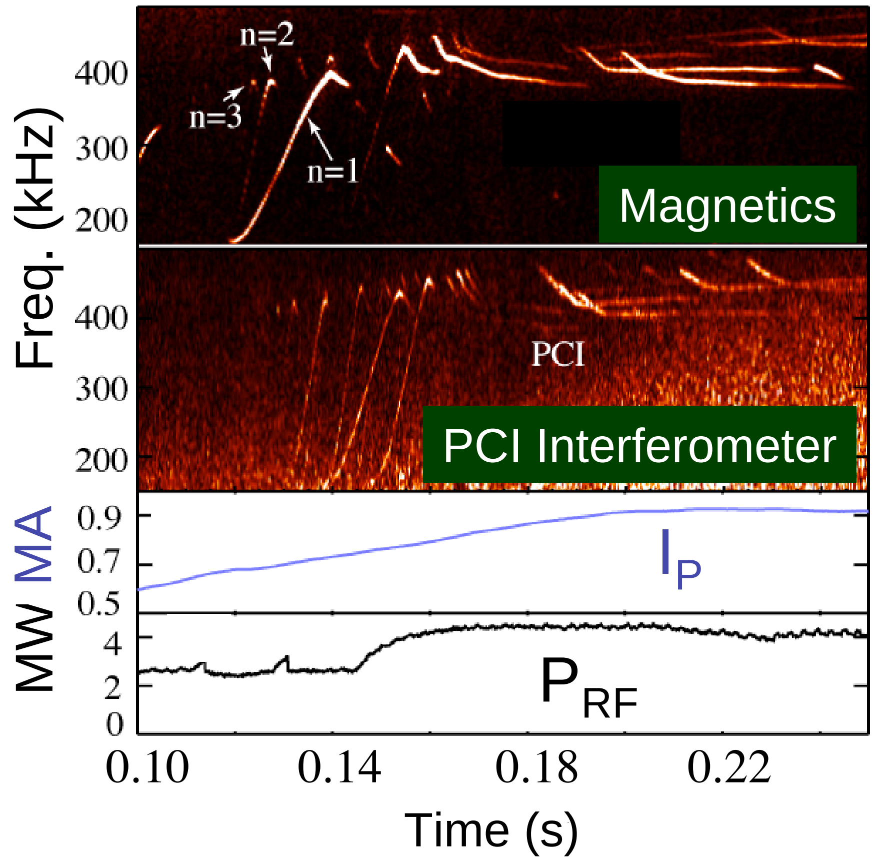


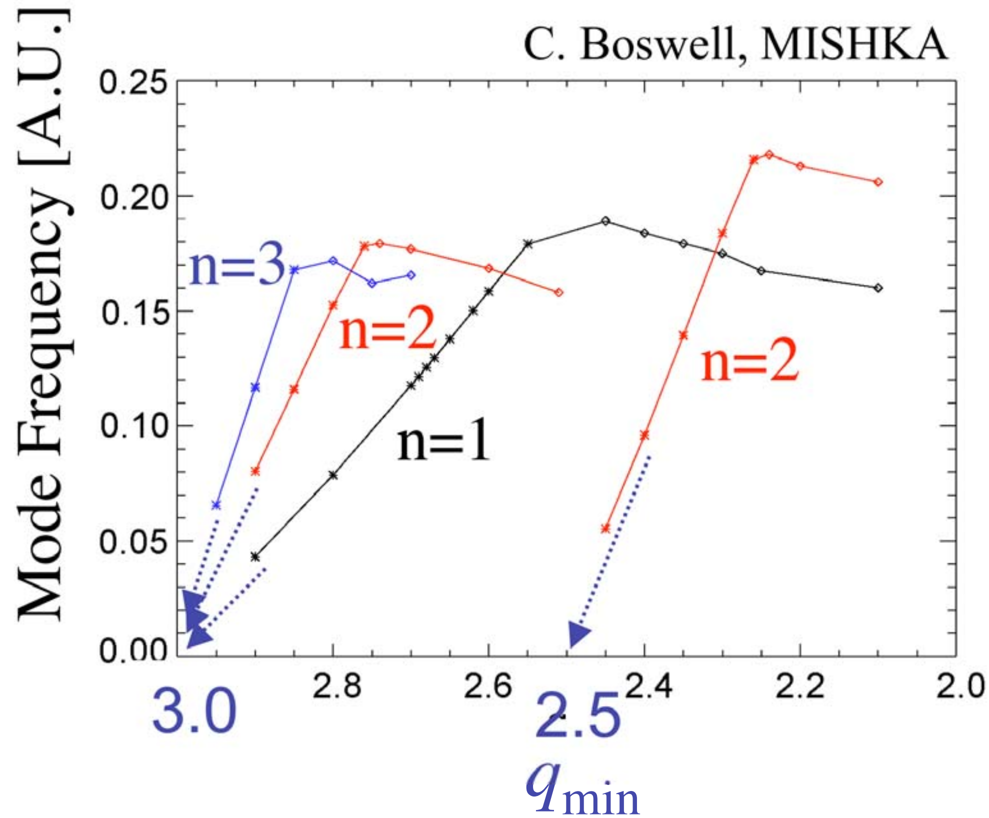
TAE modes in low density ICRH heated discharges in ASDEX-Upgrade
EX-P/4-37 Borba



MHD Spectroscopy and the Evolution of q_{min} in the Current Rise of Alcator C-MOD

EX/5-1 Nazikian

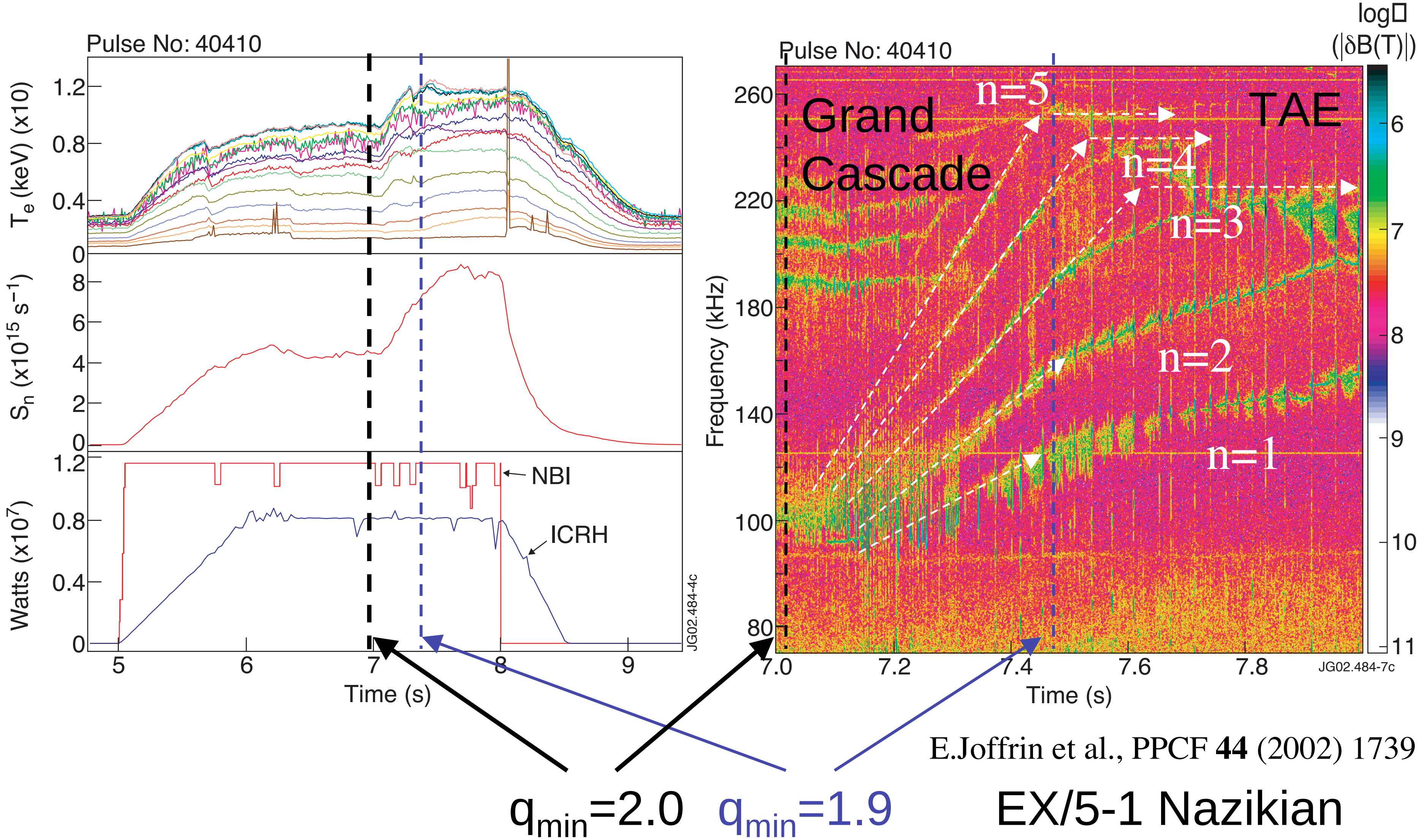




J. A. Snipes et al., Proc. 31st EPS (2004)

- MHD spectroscopy useful when MSE is challenging
- Higher-n gives higher q_{min} resolution
- Core fluctuations measurements access higher-n

Application of MHD Spectroscopy:
Onset of ITB Triggered by Integer q_{min} Crossing on JET

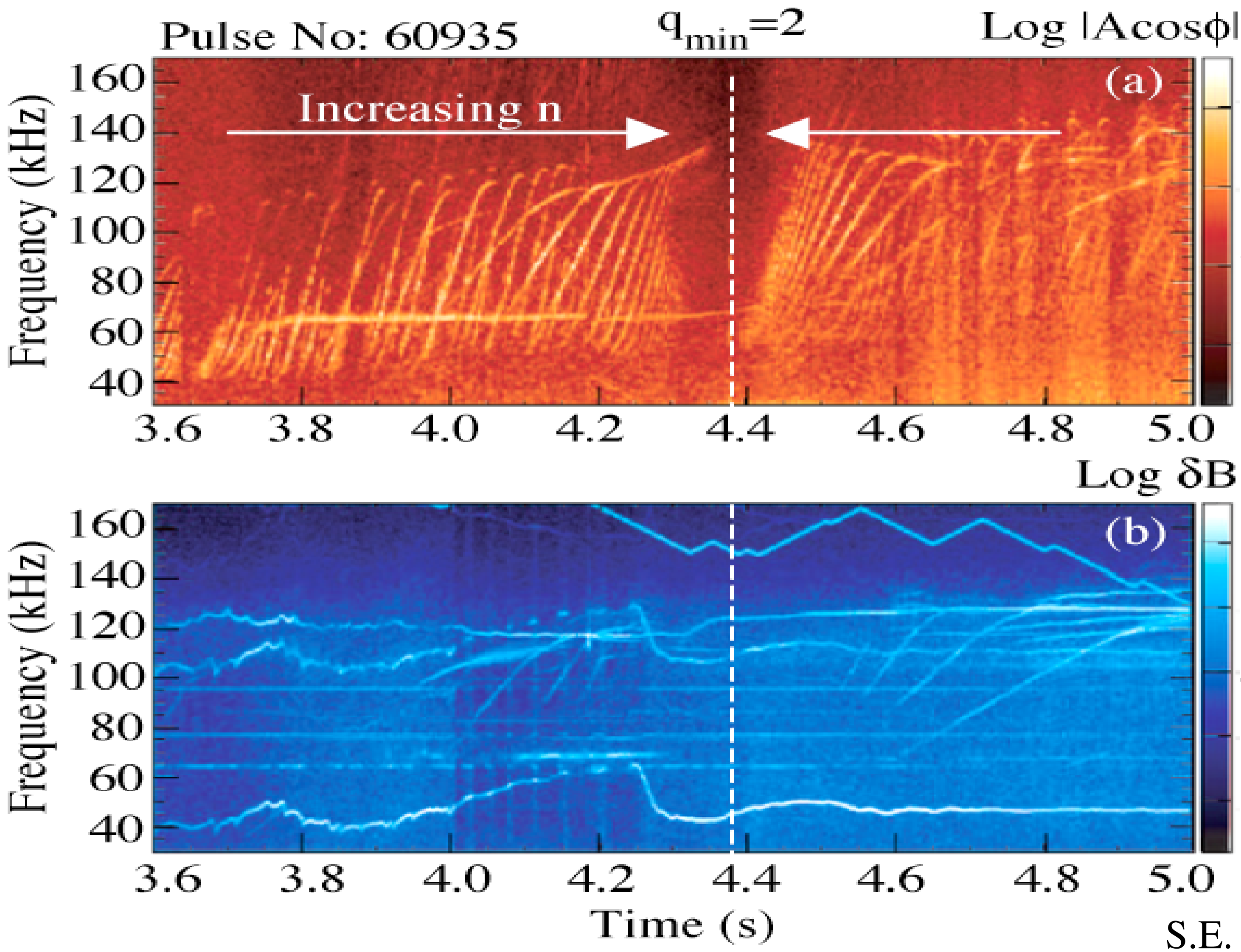


E.Joffrin et al., PPCF **44** (2002) 1739

EX/5-1 Nazikian

- What role do Cascades play in ITB triggering ?

Breakthrough: Interferometer Measurements Reveal Many Hidden Modes in Reverse Shear Plasmas on JET



- Interferometer n >16
- Reflectometer

$\tilde{B}/B \approx 1.5 \times 10^{-4}$ for n=3

- Magnetics n < 5

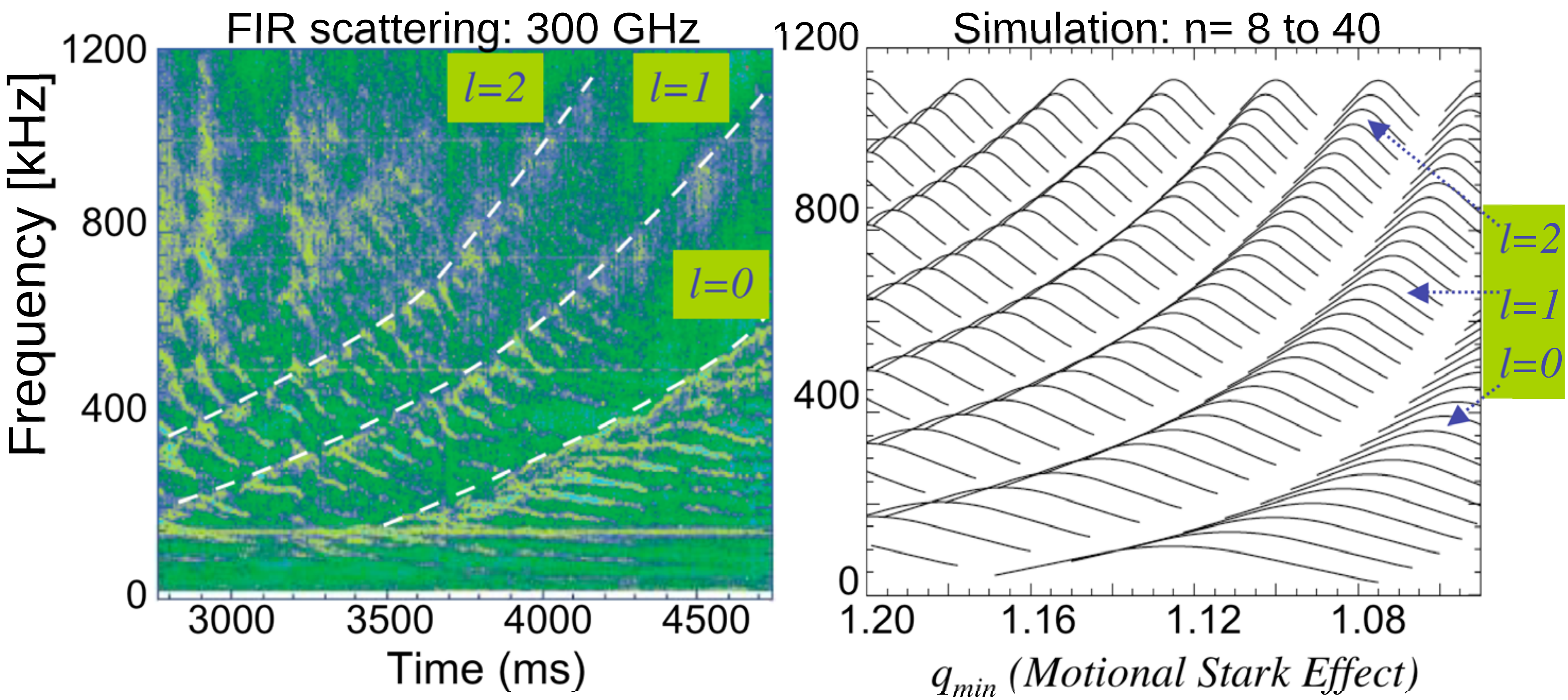
EX/5-1 Nazikian
EX/5-2Ra Sharapov

- Fast ion loss not observed

S.E. Sharapov et al., PRL **93** (2004) 165001

A “Sea of Alfvén Eigenmodes” Observed in DIII-D Plasmas Driven by 80 keV Neutral Beams

EX/5-1 Nazikian



- Bands of modes $m=n+l$, $l=0, 1, 2, \ldots$: $w_{n+1}-w_n \approx w_{rot}$ (CER)
- Neutral beam injection opposite to plasma current: $V_{||} \approx 0.3 V_A$
- 8 <n< 40, k_q up to 2.0 cm^{-1} (Turbulent scale length !!)

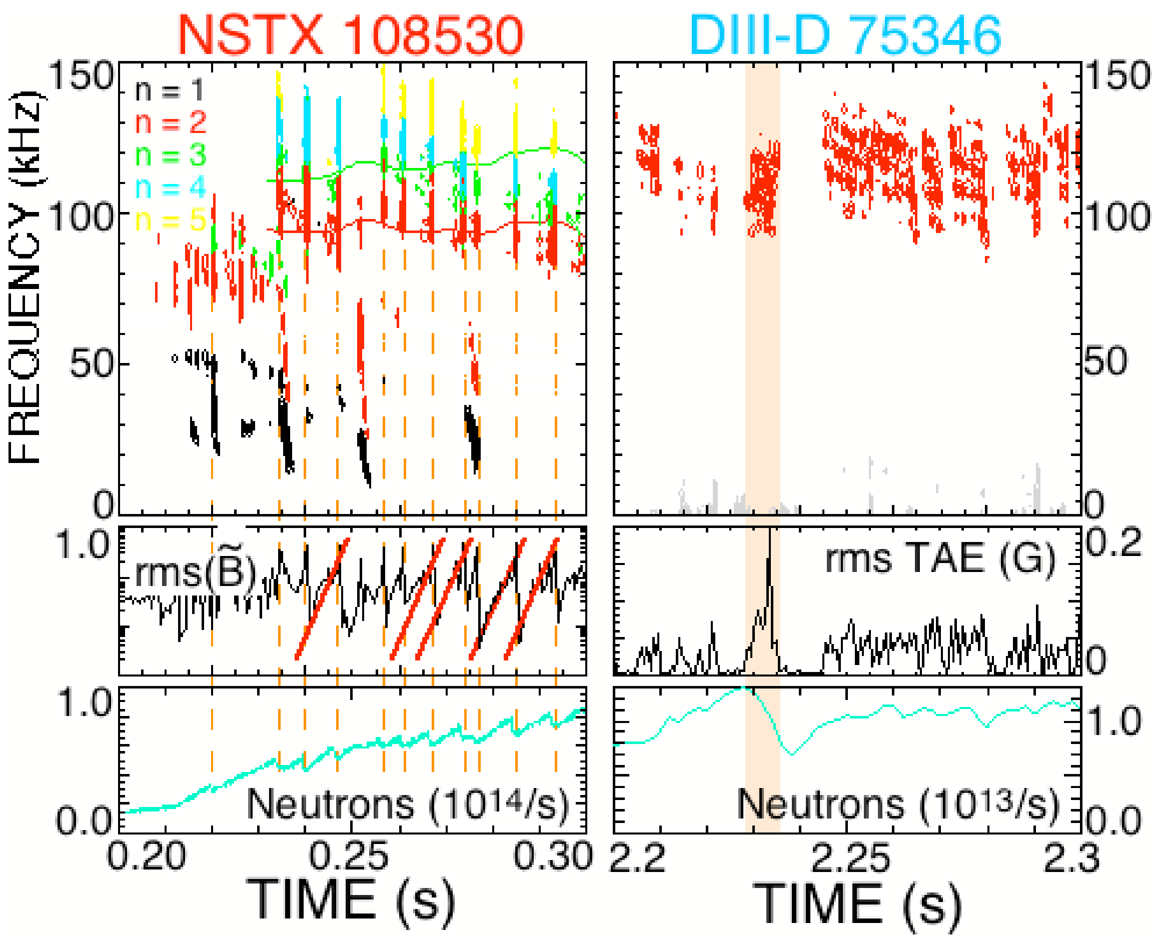
TAE can cause significant losses at both low and high aspect ratio,

- Largest losses occur with multiple unstable modes.

On NSTX:

- TAEs most virulent in low-shear, q(0) ≈ 2 regime*.
  - TAE seen at toroidal b's greater than 20%.
  - Observed growth rates in good agreement with NOVA estimates.
  - Up to 15% drops in DD neutron rate from TAE.
- With higher shear, TAE not bursting
  - no enhanced fast ion loss

EX/5-3 Frederickson



*N.N. Gorelenkov, et al., Phys.Plasmas **7** (2000) 1433.

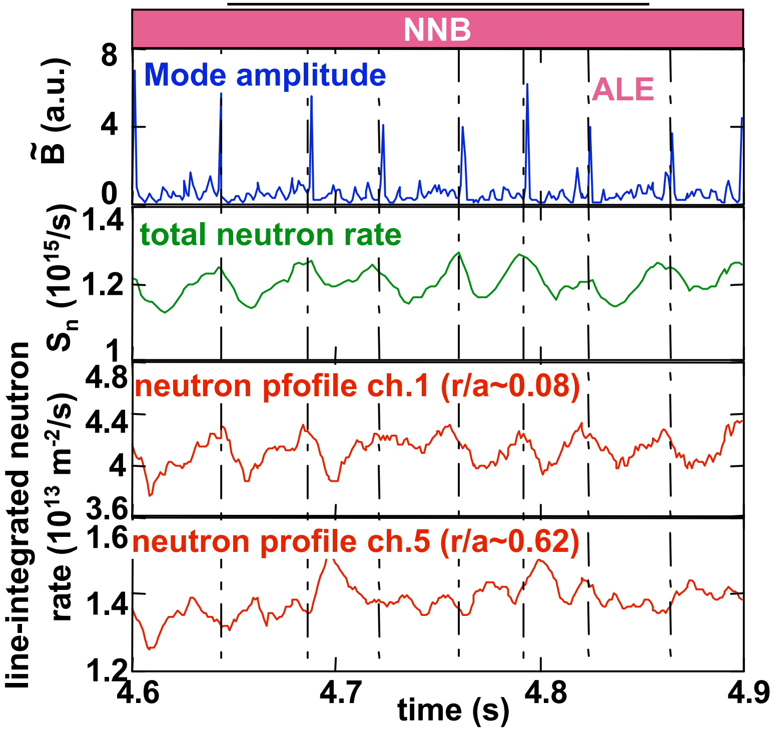
Confinement of energetic ions at ALE

K. Ishikawa (EX/5-2Rb, Thu., poster Fri.)

JT-60U

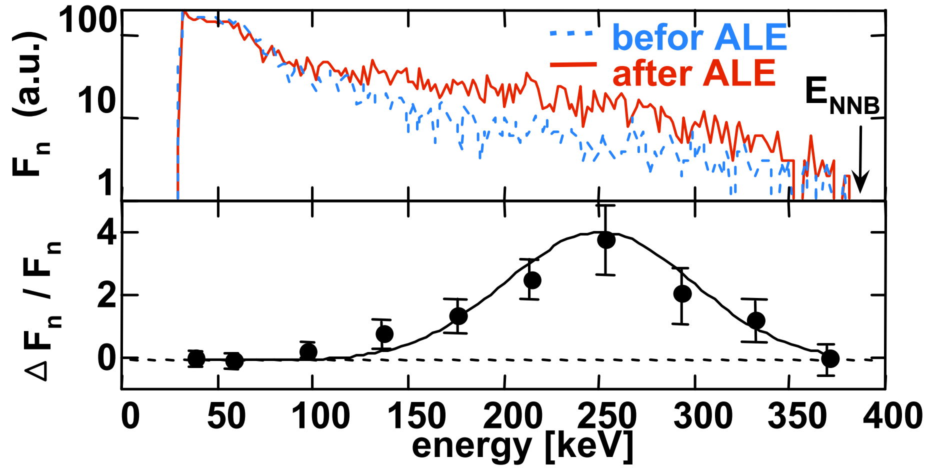
E43014, Ip=0.6MA Bt=1.2T
P_{NNB}~ 4.8MW, ENNB~387keV

<neutron emission>



- In a JT-60U weak shear plasma, N-NB drives bursting mode in the TAE freq. range.
  => Abrupt Large Event (ALE)
- **How are energetic ions affected?**

<energy distribution of neutral particle>



- Only ions in limited energy are affected.
  =>Agrees with AE resonant condition

=>Contribution to theory/modeling towards burning experiments.

EX/5-4Rb

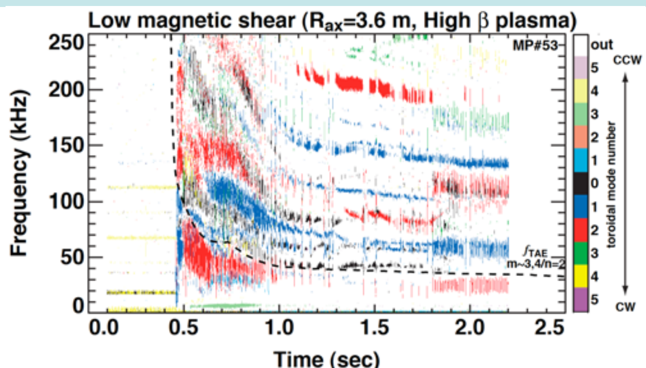
Configuration Dependence of Energetic Ion Driven Alfvén Eigenmodes in the Large Helical Device

S. Yamamoto[1], K. Toi[2], N. Nakajima[2], et. al.,
1) *Institute of Advanced Energy, Kyoto University, Uji, Japan*
2) *National Institute for Fusion Science, Toki, Japan*

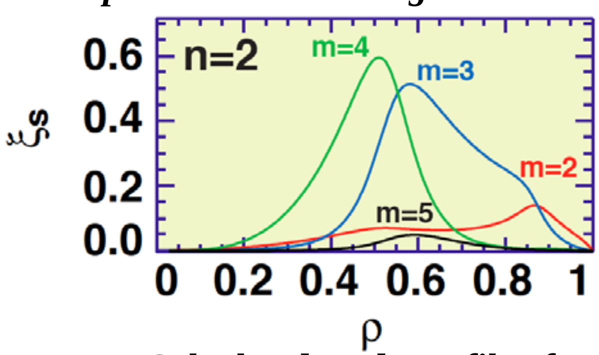
◆ Motivation

It is important to clarify the configuration dependence of Alfvén eigenmodes (AEs) because the existence and stability of them sensitively depend on the profiles of the rotational transform $\iota/2\pi$ and magnetic shear s.

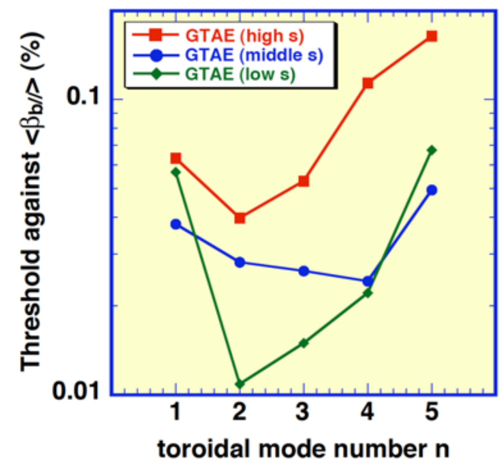
➔ **We have experimentally studied the AEs in various magnetic configurations (high, middle and low s).**



Time evolution of toroidal mode number of AE in the plasma with low magnetic shear



Calculated mode profile of bursting TAE with n = 2

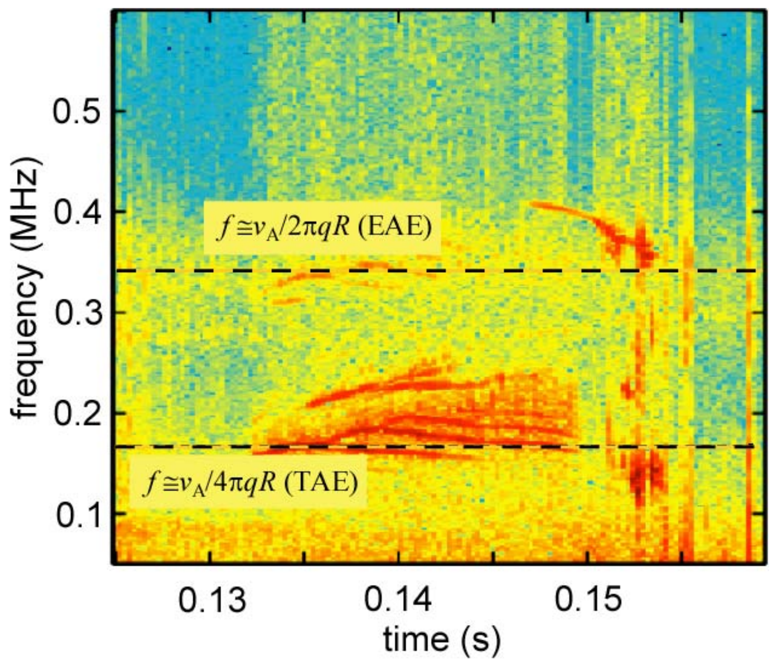


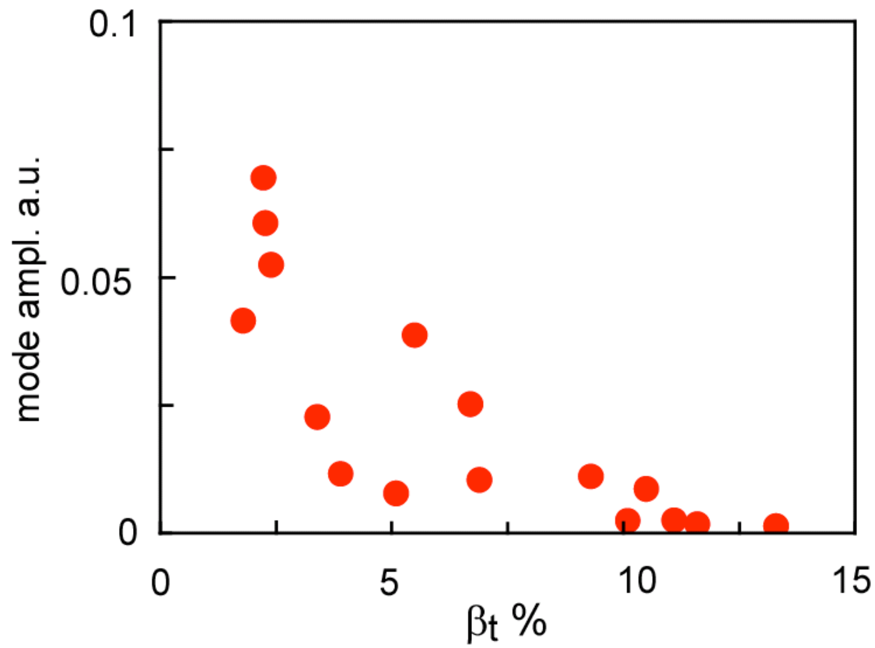
Mode number dependence of threshold of observed TAE

◆ Conclusion

Continuum damping, of which damping rate is related to the magnetic shear and toroidal mode number *n* ($\gamma_c \sim n^{3/2}$ and ~ s), would be the most important damping mechanism in the LHD plasma.

EPM activity reduces with β on MAST





For β > 5% TAE and EAE activity become dominated by non perturbative down-frequency chirping modes

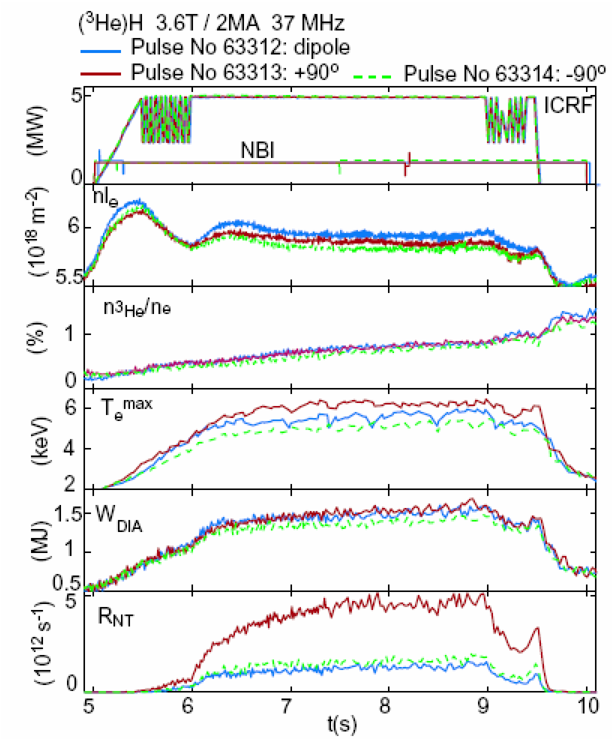
The **amplitude of these modes falls sharply with increasing β**, vanishing for β > 15%

⇒ AE activity likely to be absent in a future ST device where β on axis would approach 100%

See S. Sharapov EX/5-2Ra

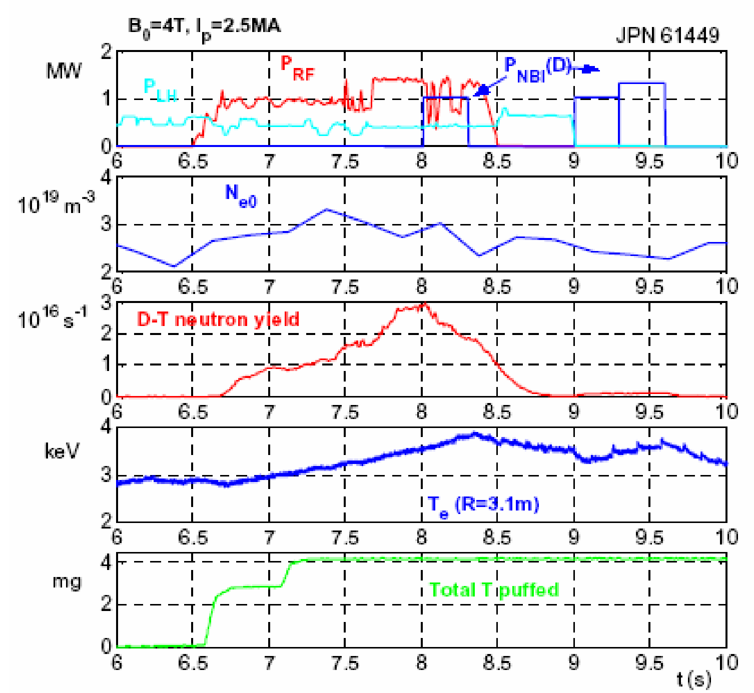
Validation of key ICRF scenarios for ITER are being carried out

(^{3}He)H used on JET for pre-activation experiments in ITER



+90 deg phasing more efficient due to improved ion orbits

(T)D used when T experiments begin

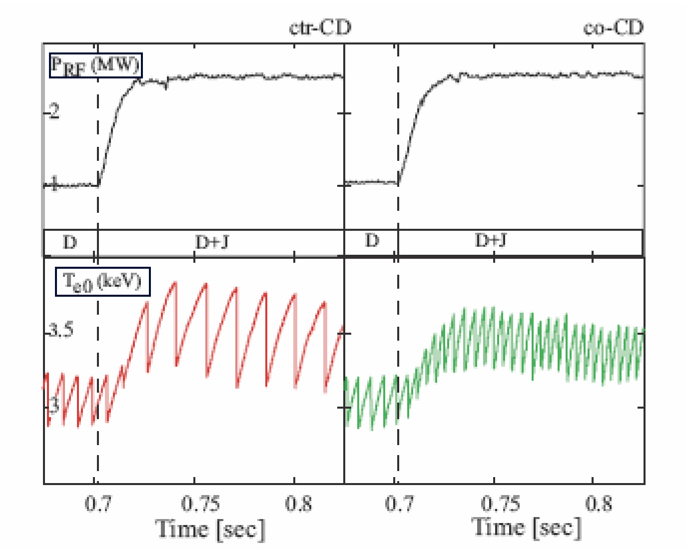


strong increase in reactivity observed with 1.4 MW ICRF

EX/P4-26 Lamalle

ICRF is useful in experimental applications

Mode conversion current drive



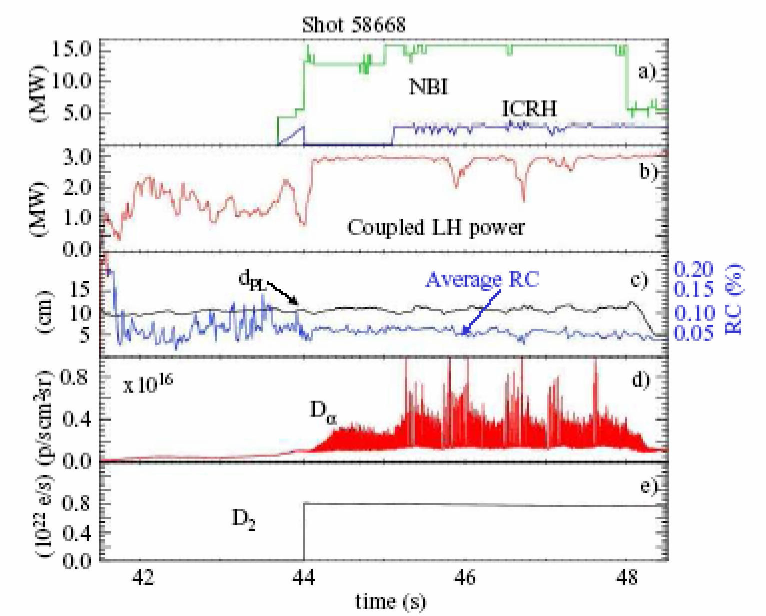
sawtooth control found in Alcator C-Mod

- Direct launch IBW in FTU (OV/4-6 Gormezano)
- Heating from ICRF (H)D found in Globus-M (EX/P4-24 Gusev)
- Fundamental heating of H found in T-11M (EX/P4-29 Maltsev)
- FWCD for heating on NSTX, but edge absorption a problem (OV2-3 Kaye)

EX/P4-32 Porkolab; TH/P4-35 Wright

ITER relevant coupling of Lower Hybrid Waves

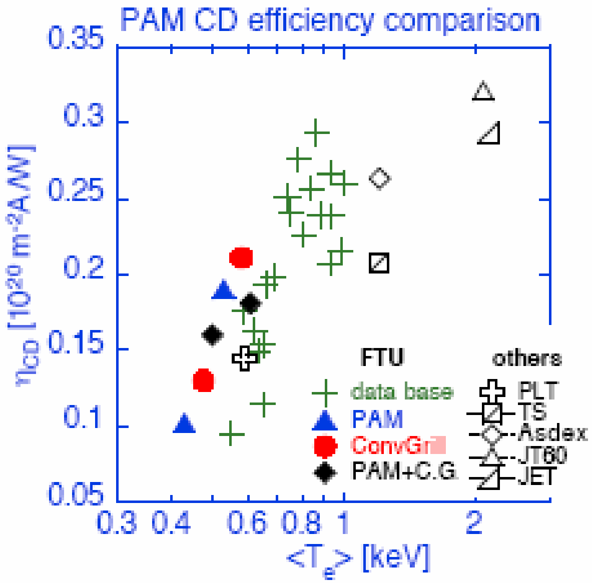
D injection improves LH coupling over large gap



3 MW coupled, but D affects ELMs
Doesn't affect ITB

EX/P4-28 Mailloux

Successful use of PAM obtained in FTU

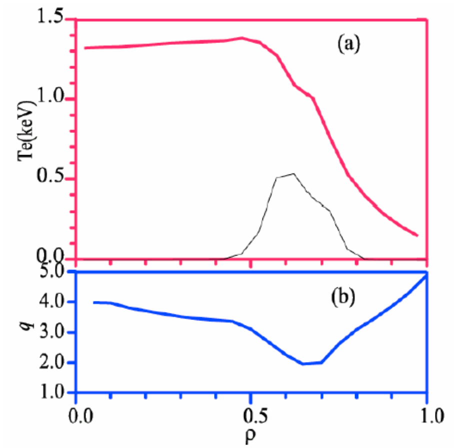


Efficiency of PAM equal that of other antennas(EX5/5 Pericoli)

Multijunction antenna with improved directionality successfully used in HT-7 (EX/P4-19 Ding)

LHCD is useful in present experiments

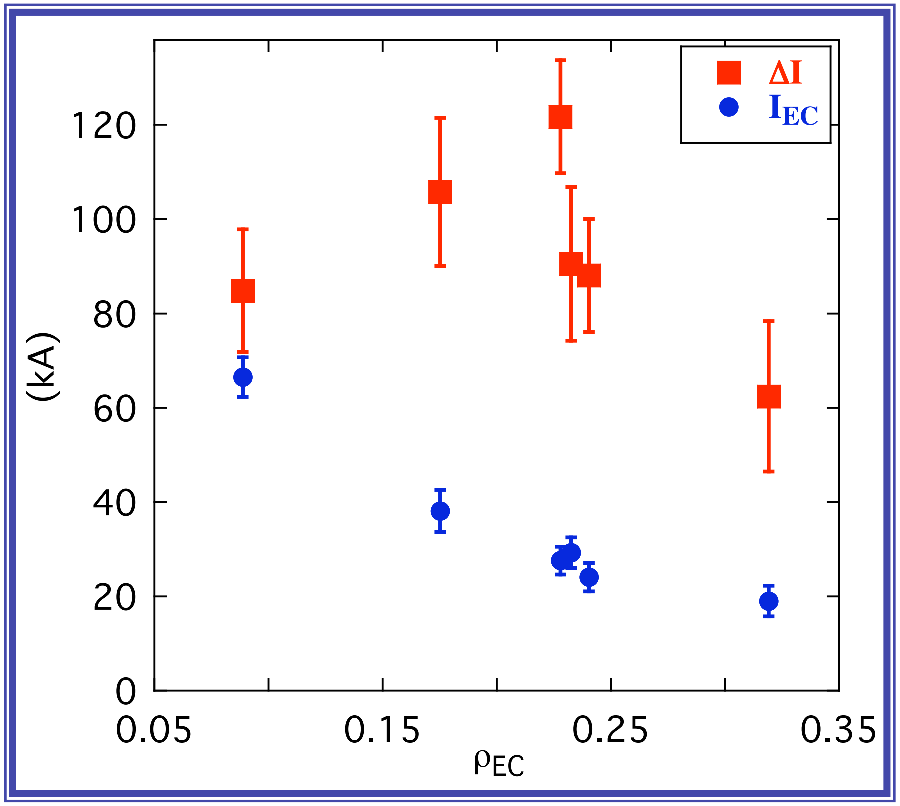
- **Control of CD location by phase control found on JT-60U**
- **6.5 minute discharge sustained by LHCD on Tore Supra**
- **5.6 hour discharge sustained by LHCD on TRIAM-1M**
- **H-mode by off-axis LHCD in HT-7 (OV-1Rb, Wan)**
- **Current profile by LHCD used on HL-2A to generate RS**



EX/P4-21 Gao

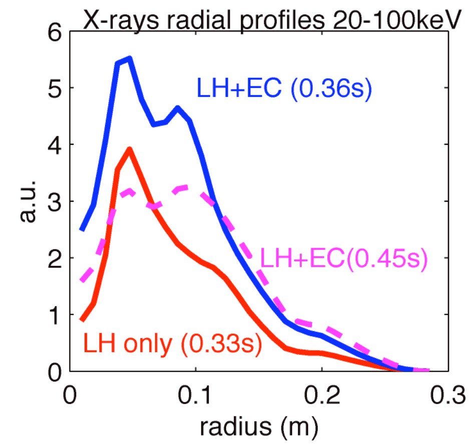
Synergy between RF waves can increase current drive efficiency

EX/P4- 22 Tore Supra Giruzzi LHCD + ECCD

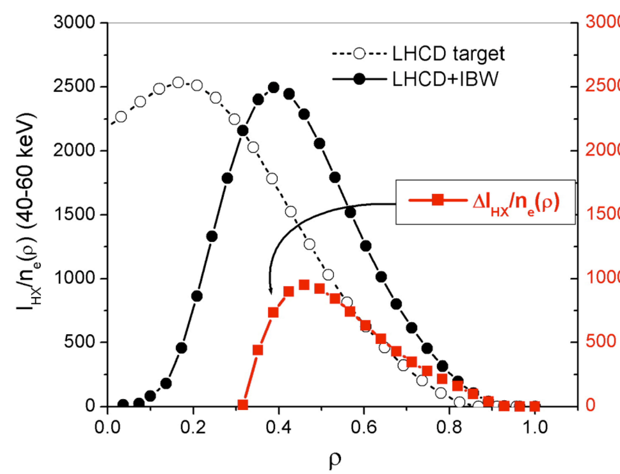


Synergy when LH and EC waves absorbed at same location

OV/4-6 FTU Gormezano

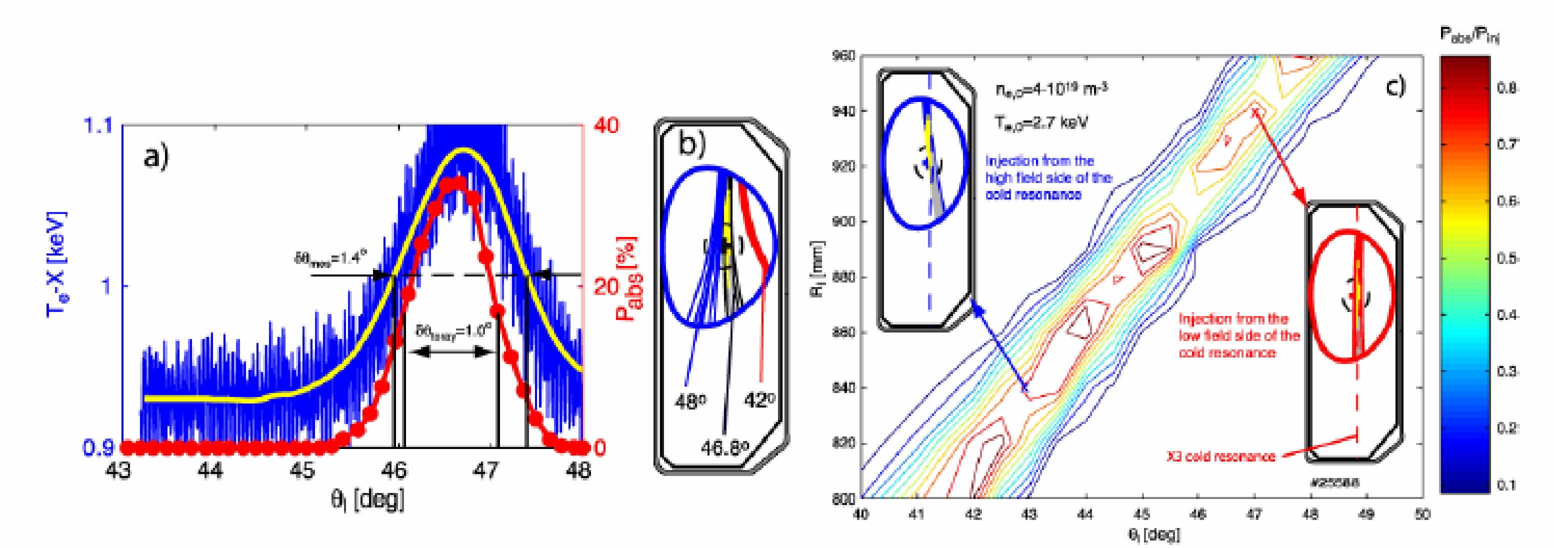


OV/5-1Rb HT7 Wan LH + IBW



ECH predictability is addressing the extremes

Third-harmonic, top-launch, ECRH experiments on TCV Tokamak



Theory and experiment are well coordinated
Feedback system successfully used

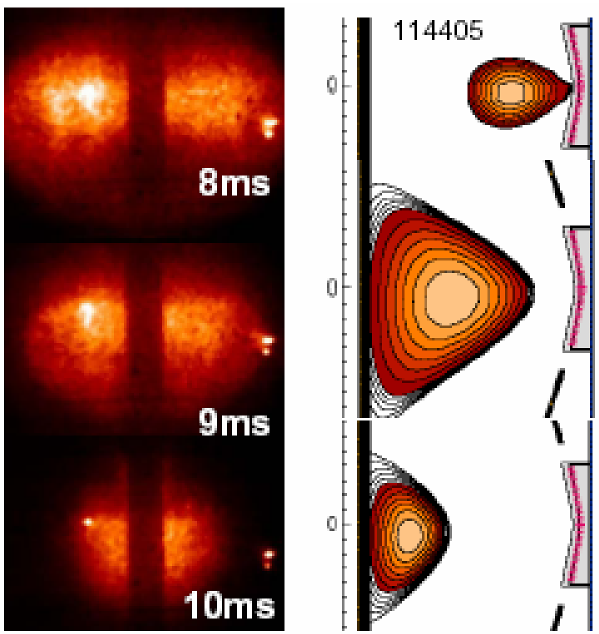
EX/P4-17 Alberti

Toroidal Current Generated Without a Solenoid

Non-solenoidal current generation/sustainment essential in future ST

1) PF-only startup

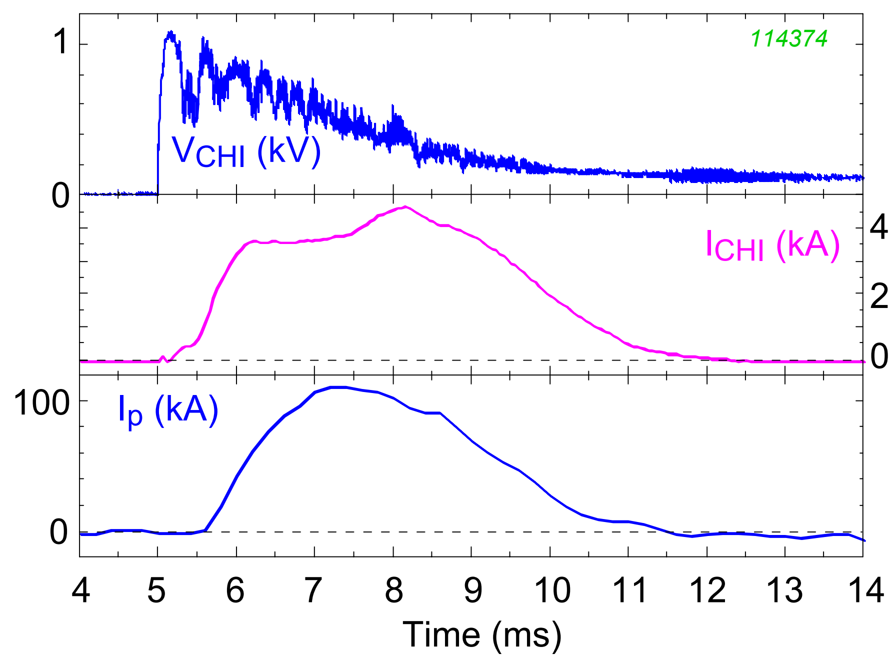
- 20 kA generated



Goal is to maintain plasma on outside where V_{loop} is high

2) Transient Co-Axial Helicity Injection

- I_p up to 140 kA, $I_p/I_{injector}$ up to 40



Goal is to extend I_p beyond duration of $I_{injector}$

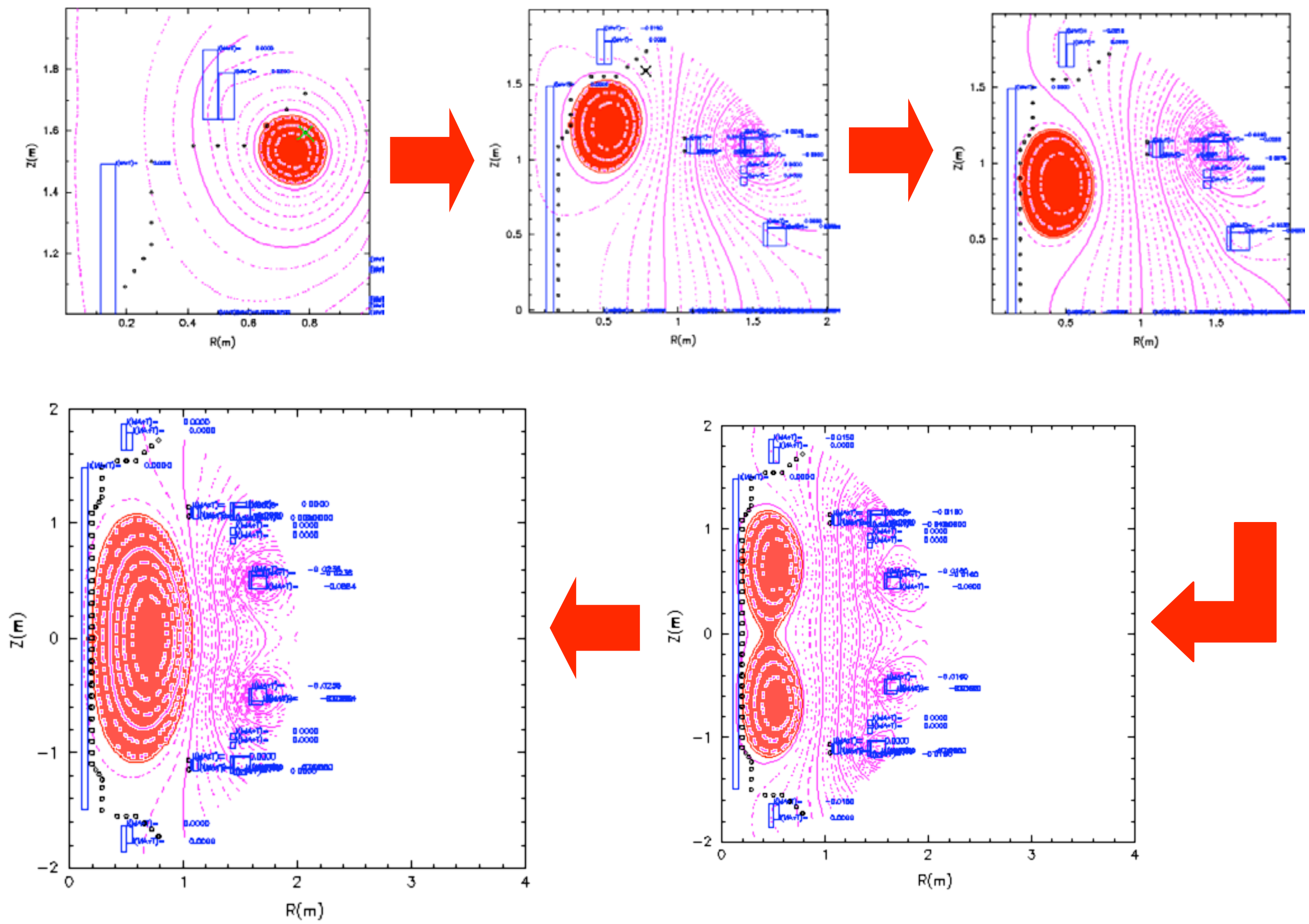
Alternative start-up schemes investigated

One such scheme is being developed in association with ENEA

Double-null merging (DNM) involves **breakdown at a quadrupole null** between pairs of poloidal coils in upper and lower divertor

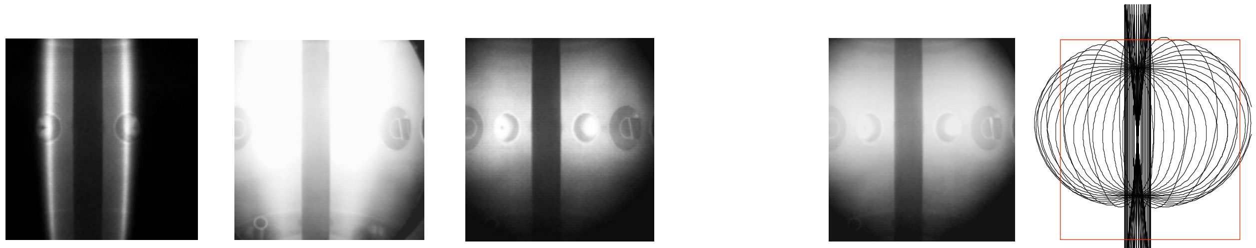
Modelling predicts **merging of plasma rings** as current in coils ramped to zero

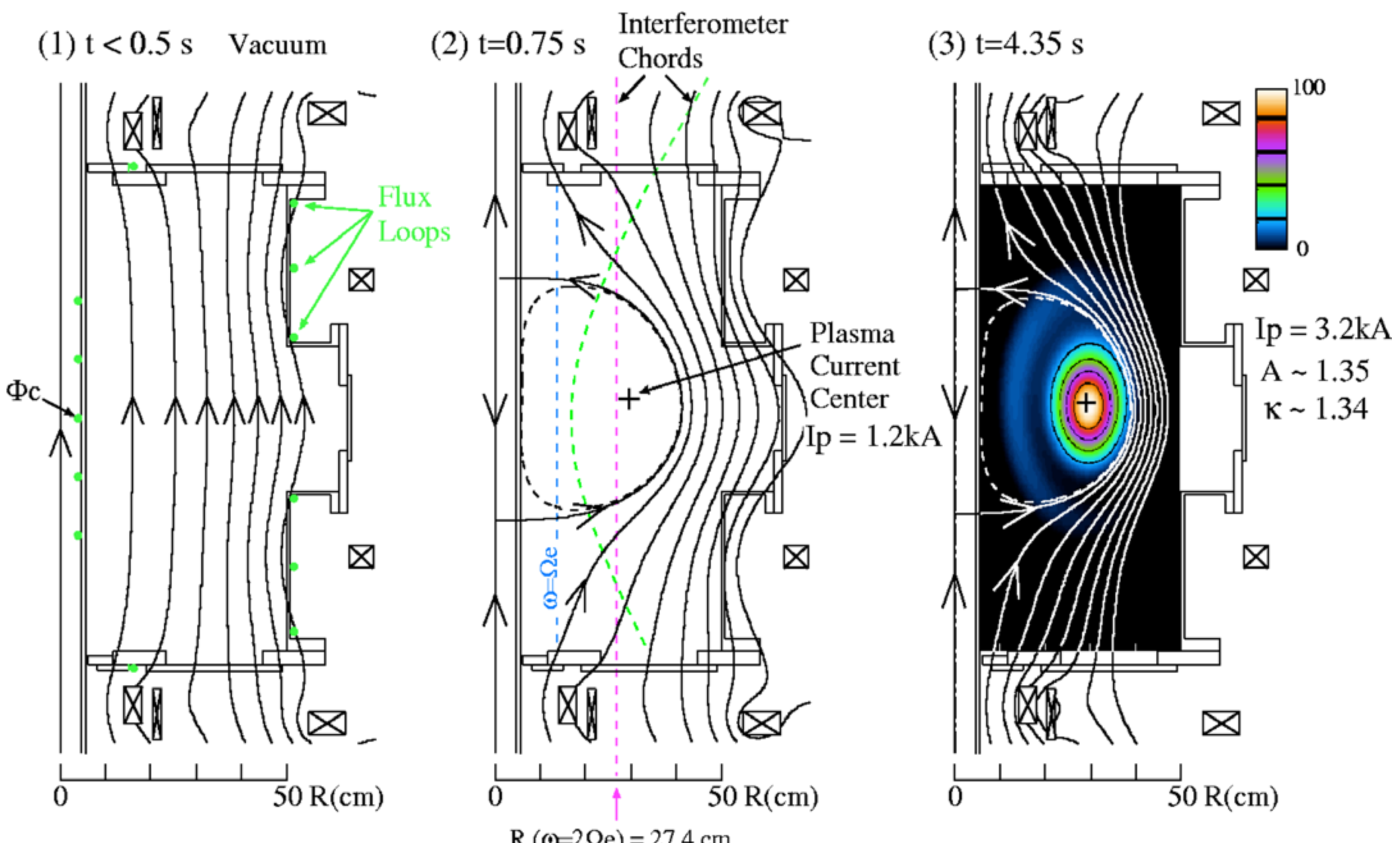
DNM is compatible with future ST design



OV/2-4 MAST Counsell

Transformerless Startup by ECH and Bv in LATE EX-P/4-27 Maekawa



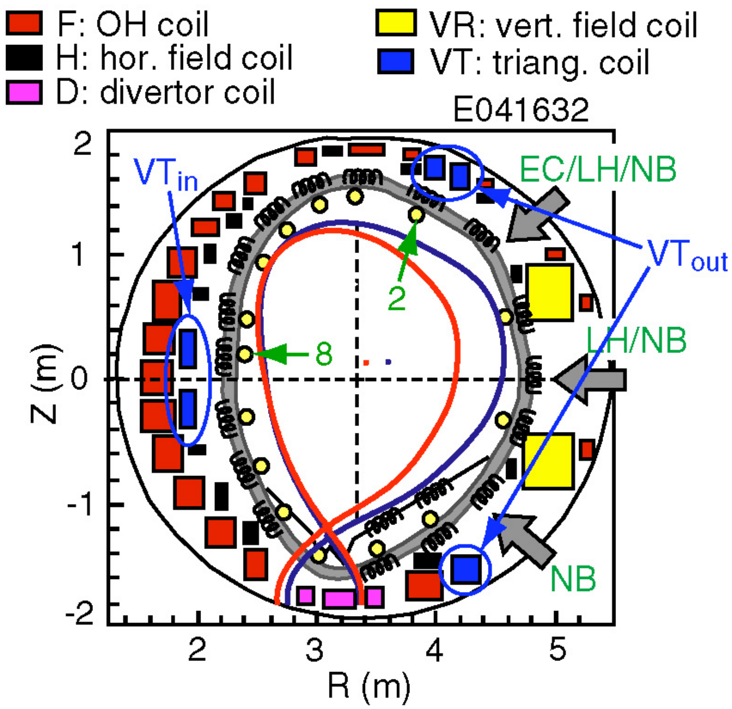


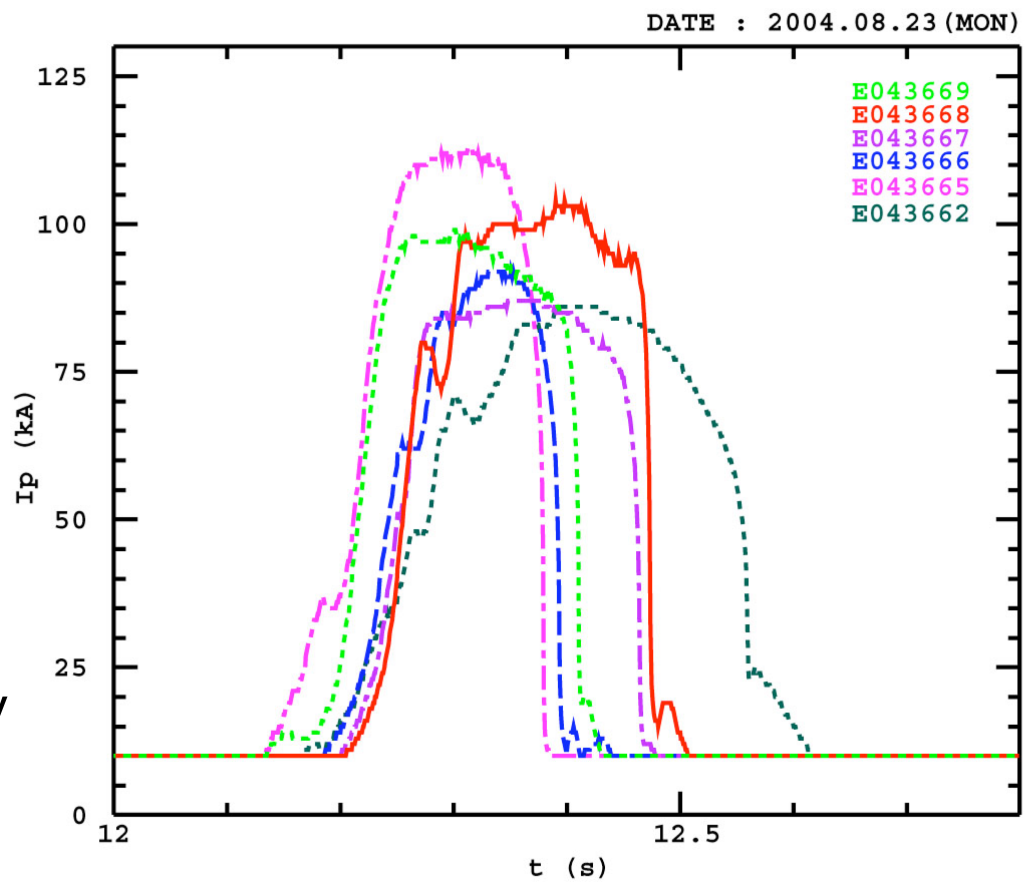
2nd Harmonic EC Heating by EBW

SX CT Image

Completely CS-less Start-up in JT-60U

100 kA maintained for 0.2 sec





- Start-up with VR and VT$_{out}$ only (VT$_{in}$ coil not used)
- With strong enough EC ionization, Ip starts up with Bv in the negative direction (no field null)

EX/P4-34 Y. Takase, et al.

How is the dynamo current generated in the RFP?

$$\langle E \rangle + \langle \tilde{v} \times \tilde{B} \rangle - \frac{\langle \tilde{j} \times \tilde{B} \rangle}{ne} = \eta \langle j \rangle$$

MHD dynamo

The standard model

Hall dynamo,

two-fluid effect

significant in quasilinear theory

OV/4-2 MST Prager

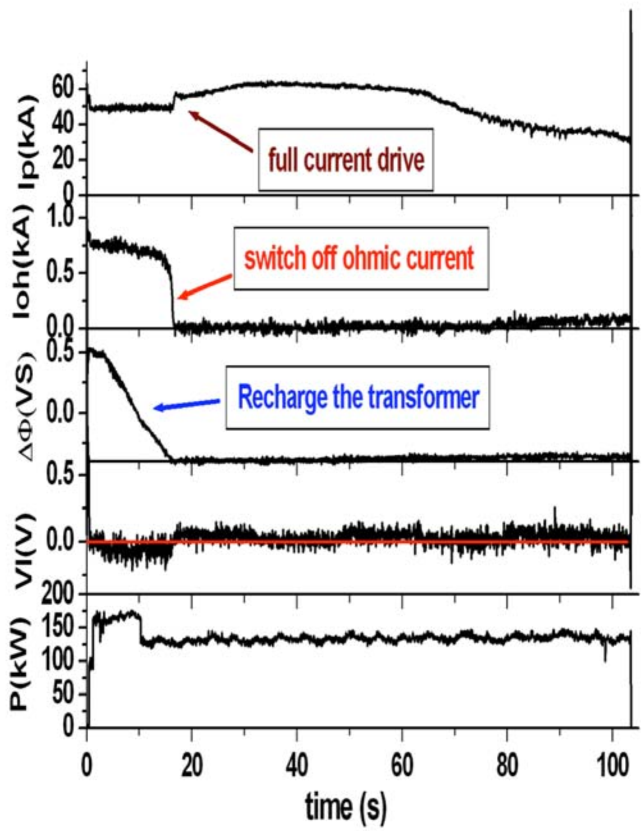
j and B measured by Laser Faraday Rotation

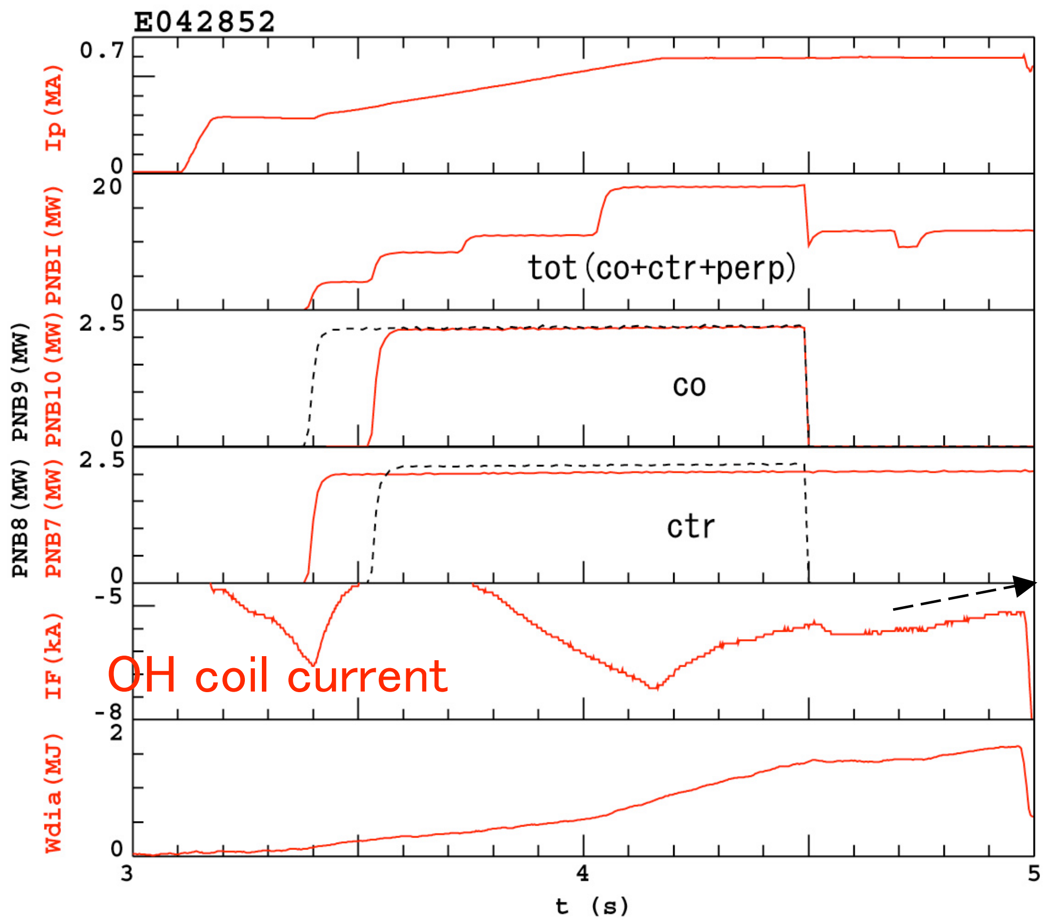
(UCLA)

Transformer Recharging by Excess Non-Inductive Current Drive

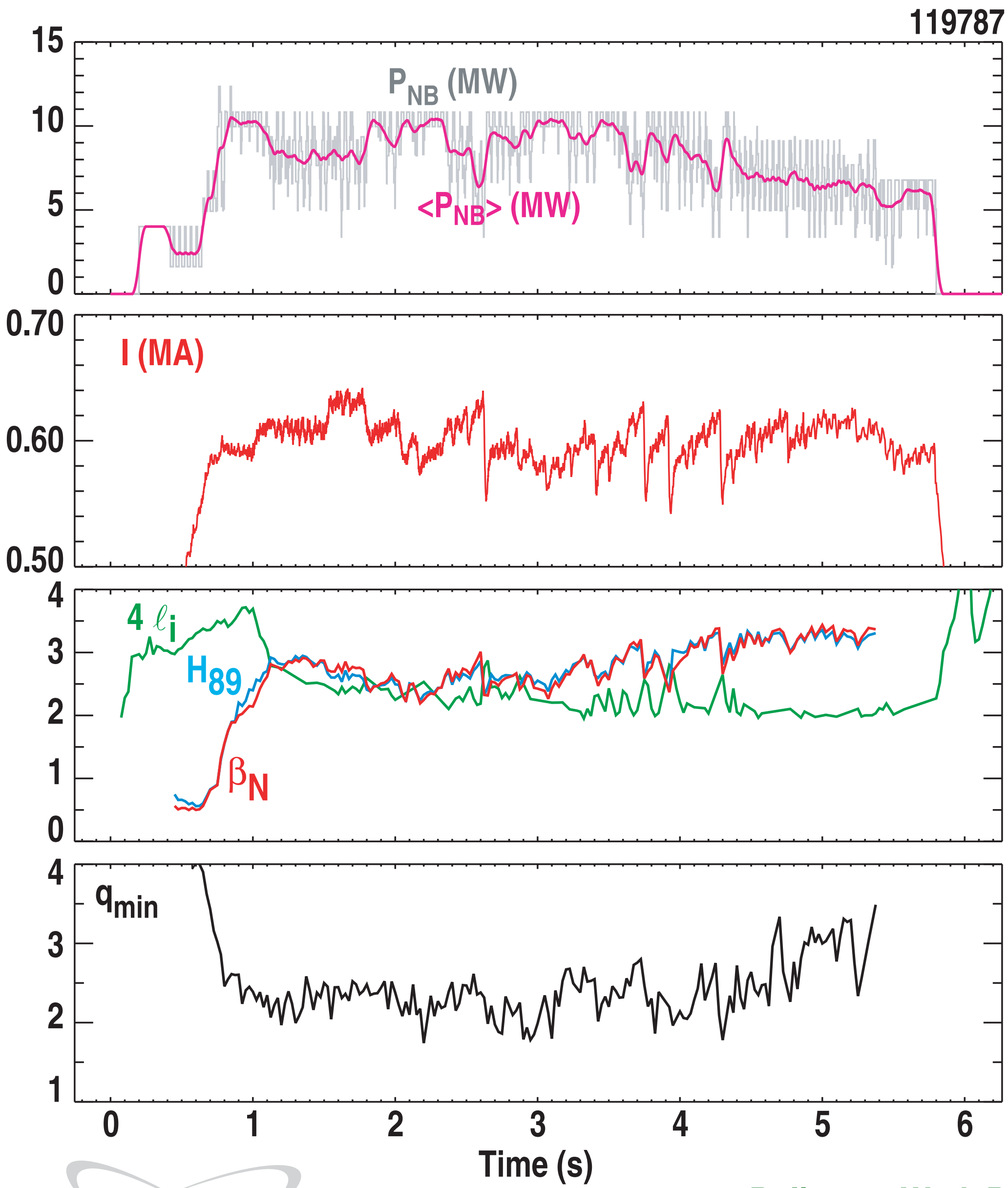
Bootstrap Overdrive EX-P/4-34 JT-60U Takase

LHCD OV/5-1Rb HT-7 Wan





TRANSFORMERLESS OPERATION SHOWS CONTROL OF HIGH BOOTSTRAP FRACTION PLASMAS WILL BE CHALLENGING



- The desired steady-state operating point may not be a stationary solution to the coupled fluid equations. If not, active control is required.
- Inductive control of the plasma current may be desirable ⇒ non-inductive overdrive will be required.
- At high safety factor (q_{95}~10) and high qmin (~3), the bootstrap current fraction is >80%.

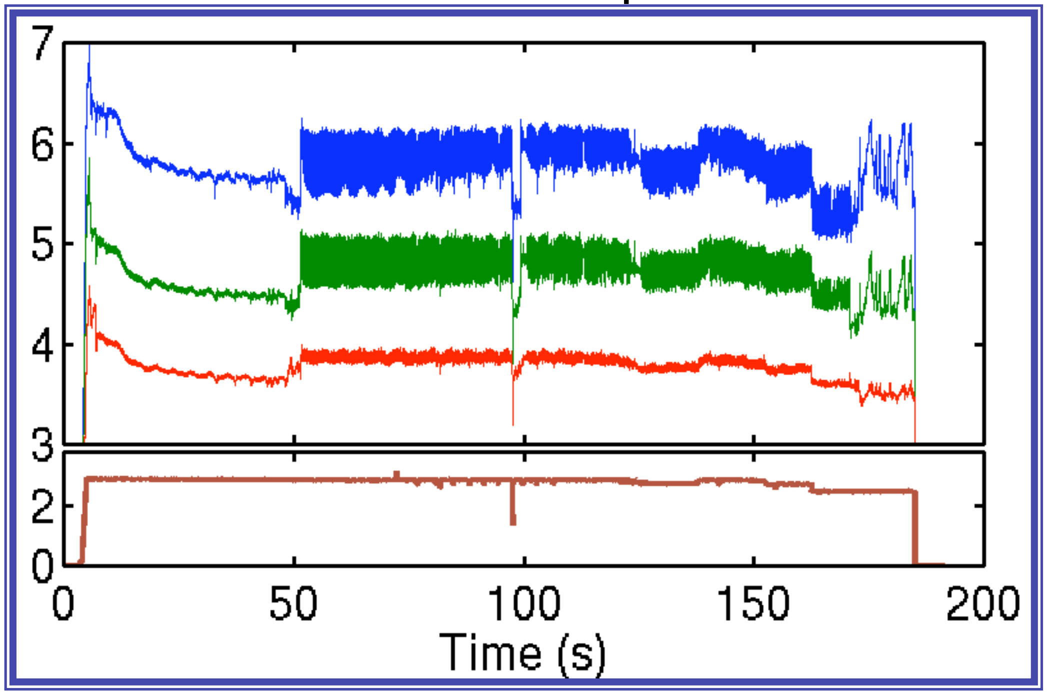
Politzer – Wed. PM Poster

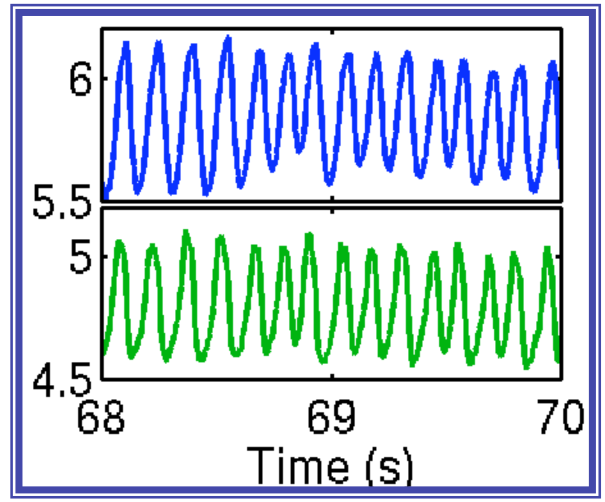
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

248-04/TCL/rs

Long Time Scale Oscillations

Temperature Oscillations in Tore-Supra
Poster EX/P6-16 Tore-Supra Imbeaux et al.





Radial structure, low frequency (a few Hz)

Non linear interplay between transport and current profile at the onset of the core ITB

➔RT control of current profile required (for ex, ECCD)

See also150 second PWI related oscillations in TRIAM-1M OV/5-2 Zushi

SUMMARY CONCLUSIONS

RWM – Progress in fundamental understanding and direct feedback with low rotation.

NTM - ECCD suppression becoming an application.

Disruptions – Massive Gas Injection mitigates all consequences.

ELMS – Peeling-Ballooning Model Converging.
Many avenues of approach to tolerable ELMS.

Stability - Stellarator Beta limit studies beginning.

Alfven – Internal plasma diagnostics show modes more pervasive than was thought.

Waves - Synergy between waves can increase current drive efficiency.

Current Drive – Long pulse, transformerless operation challenging for the future.