統合コード研究会
九大応力研, 2004/3/19

MHD、ディスラプションとその制御に関する
第4回ITPA会合の報告

N. Nakajima
NIFS

- 会合の概要
  - ○ US/JPワークショップ "MHD stability control of toroidal plasmas"
  - ○ Large Tokamak ワークショップ "Physics of current hole"
  - ○ 第4回ITPA Topical Group 会合 "MHD, Disruption and Control"
    Tokamak Physics Basis の執筆内容の検討が主体
- 議論における注目点
- 物理サブクラスターの活動に関して

Feb. 2, Ver.10 final

US/Japan workshop on "MHD Stability Control of Toroidal Plasmas"(FP2-2), Large Tokamak workshop on "Physics of Current Hole" (W56) and The Fourth Meeting of the ITPA Topical Group on MHD, Disruption and Control

Naka JAERI, Japan 2 – 6 February 2004

MONDAY, 2 FEBRYARY ITER Conference Building

8:50 Registration
9:00 Welcome address : M.Kikuchi (JAERI)
9:05 K.Yamazaki(NIFS), Opening of workshop on US/Japan workshop on MHD Stability

Stability in helical system and control **Chairman: K.Yamazaki**
9:15 E. Lazarus (ORNL): Plasma Control Requirements for the NCSX Stellarator
9:45 K. Watanabe(NIFS): The effects of Ideal Interchange Mode on Operational Regime in LHD Experiments
10:15 Y. Narushima (NIFS): MHD stability of LHD plasma with large plasma current
10:45 E. Lazarus (ORNL): Design of Magnetic Equilibrium Diagnostics for Stellarators
11:15 C.Suzuki (NIFS): Effect of Toroidal Current on MHD Stability for N=2 Quasi-Axisymmetric Stellarator
11:45 N.Nakajima(NIFS): Ideal MHD spectra in Heliotron system

Lunch 12:15 – 13:15

Stability in innovative confinement concept **Chairman: E.Lazarus**
13:15 J. Manickam (PPPL): Role of fast plasma rotation on MHD physics in NSTX'
13:45 A. Ishida (Niigata Univ): Theory of Flowing Two-Fluid Equilibrium and Its Application to ST
14:15 E. Fredrickson (PPPL): MHD issues in NSTX
14:45 N.Mizuguchi (NIFS): MHD properties of spherical torus plasma with flow

Break 15:15 – 15:30

Non-ideal and Non-linear MHD Stability Behavior **Chairman: J.Manickam**
15:30 S.Yamaguchi (Kyoto Univ): Three Dimensional Observation of Sawtooth Crashes by Multi-Toroidally-Positioned SXCT system
16:00 E. Lazarus (ORNL): Comparison of Sawteeth in Bean and Oval Shaped Tokamak Plasmas
16:30 Y. Ishii (JAERI): (tentative) Non-linear simulation of double tearing mode
16:50 Martynov (by Jo Lister)(CRPP): edge kink mode stability with a separatrix
Adjourn 17:10

TUESDAY, 3 FEBRUARY, **ITER Conference Building**

Neoclassical Tearing Mode and Steady State Issues **Chairman: E.Strait**

9:00 R. La Haye (GA): ECCD Suppression of NTMs in ITER
9:30 A.Isayama (JAERI): NTM and Steady State experiments in JT-60U
10:00 S. Guenter: Active control of MHD instabilities on ASDEX Upgrade
10:30 S. Konovalov (JAERI/ Kuruchatov): Theory of magnetic well and anomalous transport effects on NTM
10:50 N. Hayashi (JAERI): NTM simulation and prediction for ITER

Break 11:10-11:20

Stabilization and Destabilization by Wall, Error Field, Rotation and Others **Chairman: G.Navratil**

11:20 E. Strait(GA): RWM stabilization with internal coils in DIII-D
11:50 R. Granetz (MIT): Locked mode studies on C-Mod

Lunch 12:10-13:10

Chairman: R.Granetz

13:10 S.Tokuda/Aiba (JAERI): External mode analysis by MARG2D code
13:30 M.Furukawa(JAERI): A model equation for ballooning modes in toroidally rotating tokamaks
13:50 S. Jardin (PPPL): Mode rigidity of RWM

Break 14:20 – 14:20

Chairman: S.Guenter

14:20 M.Sato(NIFS): Nonlinear simulation of resistive wall modes in cylindrical tokamaks
14:40 J. Bialek (Columbia Univ.): VALEN code simulation on RWM
15:00 G.Kurita (JAERI): RWM Analyses with Ferromagnetic and Plasma Flow Effects in a Tokamak
15:20 G.Navratil (Columbia Univ.): VALEN/DCON Study of RWM Rigidity and Extension to Multi-Mode Analysis
15:40 V.D. Pustovitov(Kuruchatov): Comments on the Single Mode Model Used in VALEN Calculations

Break 16:00 – 16:20

16:20 T.Ozeki(JAERI): Opening of workshop of Current Hole **Chairman: T.Ozeki**

Equilibrium and MHD Stability of Current Hole

16:30 S. Guenter(IPP): Current hole equilibria with self-consistent current density profiles
17:00 R. Jayakumar (LLNL): Current hole Equilibrium Model of Current Hole

Adjourn 17:30

Party on Akogi-Club (2000yen per person)

WEDNESDAY, 4 FEBRUARY **ITER Conference Building**

(continued) **Chairman: R.Jayakumar**

9:00 T. Takizuka (JAERI): Axi-Symmetric Multi Islands equilibrium
9:30 S. Jardin (PPPL): Modeling of current hole plasmas
10:00 S.Cortes (IST): Current hole studies with and without equilibrium reconstructions at JET tokamak
10:30 R.Kanno (NIFS): LHD equilibrium with Zero Rotational Transform Surface
11:00 G.Huysmans(CEA): MHD Stability Simulation of Current Hole plasmas
11:30 Y.Nakamura(JAERI): TSC Simulation of Current Hole
11:50 Martynov (by Jo Lister)(CRPP): tokamak equilibria with negative core current calculated with axisymmetric islands

12:00-12:15 Summary of MHD workshop: G.Navratil

Lunch 12:15 - 13:15

Observation of Current Hole and Related Phenomena **Chairman: G.Huysmans**

13:15 N. Hawkes(UKAEA): Current Hole Studies at JET
14:00 T. Fujita(JAERI): Experimental Studies on Current Hole in JT-60U
14:45 O.Gruber(IPP): Observation of current holes in ASDEX Upgrade

Break 15:15 - 15:30

Chairman: G.Hawkes

15:30 K.Toi(NIFS): Exploration of New Magnetic Configuration with Zero Rotational Transform in the Large Helical Device
16:00 R. Jayakumar (LLNL): Curerent hole Experiments in DIII-D
16:30 N.Hayashi(JAERI):Transport Simulation of Formation and Sustainment of Current Hole
17:00 Discussion on application of current hole towards reactor:
Summary of Current hole workshop: T.Fujita (JAERI)

Adjourn 17:30

THURSDAY, 5 FEBRUARY **JT-60 Building**

Fourth ITPA Topical Group meeting on "MHD, Disruption and Control" **Chairman: O.Gruber**

9:00 - 12:00 Presentation of the sections of chapters 3&8 of the ***Tokamak Physics Basis***
(15min Coffee break)

12:00 -13:00 Lunch

13:00 - 17:30 Presentation of the sections of chapters 3&8 of the ***Tokamak Physics Basis*** (continue)
(15min Coffee break)

Adjourn 17:30

FRIDAY, 6 FEBRUARY **JT-60 Building**

9:00 -10:30 Presentation of the sections of chapters 3&8 of the ***Tokamak Physics Basis*** (continue)

10:30 10:45 Coffee break

Review of recent experimental and theoretical results (Disruption and Control)
10:45 V.Lukash: DINA code fitting of halo current in intentional JT-60U VDE shots (15 min)
11:00 R.Yoshino: Neural-Net Disruption Predictor in JT-60U. (15 min)
11:15 E. Lazarus: Thoughts on the gain matrix for plasma shape control (15 min)
11:30 V. Pustovitov: Comments on the Single Mode Model Used in VALEN Calculations (15 min)
11:45 J. Lister: Testing a magnetic correction to position drift using DINA-CH (10 min).

12:00 -13:00 Lunch

13:00 Y. Gribov: Present status of the Electronic Working Group on Control" (about 30min)
14:00 - 15:30 Discussions on joint international experiments
15:30 - 15:45 Coffee break
15:45 - 17:30 Other topics

Adjourn 17:30

SUMMARY OF US/JAPAN WORKSHOP

G. A. Navratil

Columbia University, NY, USA

US/Japan Workshop on
MHD Stability Control of Toroidal Plasmas
JAERI-Naka, Japan
2-6 February 2004

Helical Systems

- QUASI-AXISYMMETRY STELLARATORS: NCSX(BUILDING) AND CHS-QA(PROPOSED)

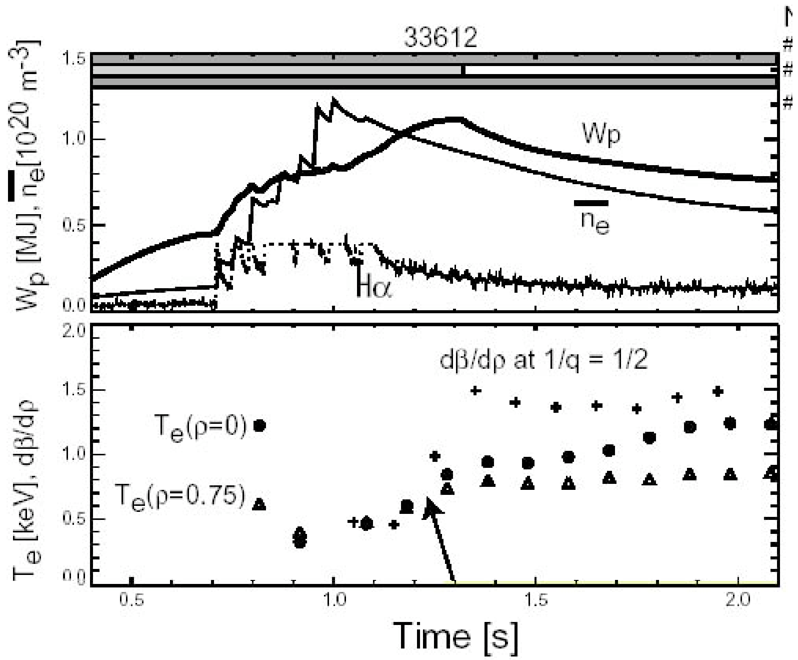
- SEEKS TO COMBINE THE “BEST” FEATURE OF TOKAMAK AND STELLARATOR:

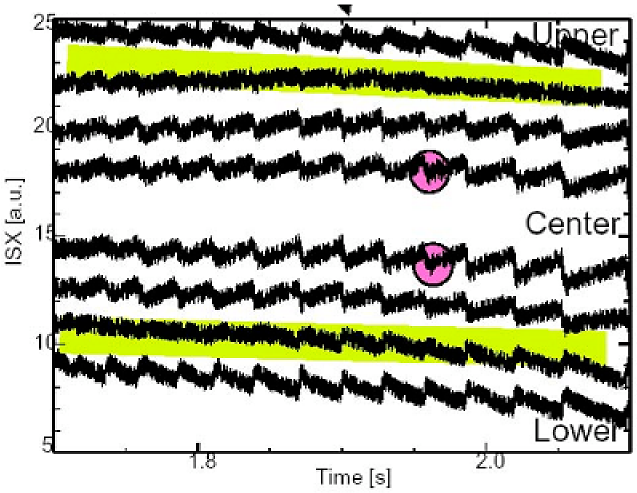
  COMBINE BENEFIT OF TOROIDAL ROTATION THRU QA WITH DISRUPTION RESISTANCE OF EXTERNAL MAGNETIC TRANSFORM.

- LHD STUDY MHD & CONFINEMENT PROPERTIES

MHD Activity in Ideal Interchange Unstable Region

▲ Pressure gradient just after pel. inj (0.75, 2.8T)





Achievement of pressure gradients in the region predicted as ideal MHD unstable

==> observation of saw-tooth oscillation as fluctuation signal

=> Achievement as Transitional State

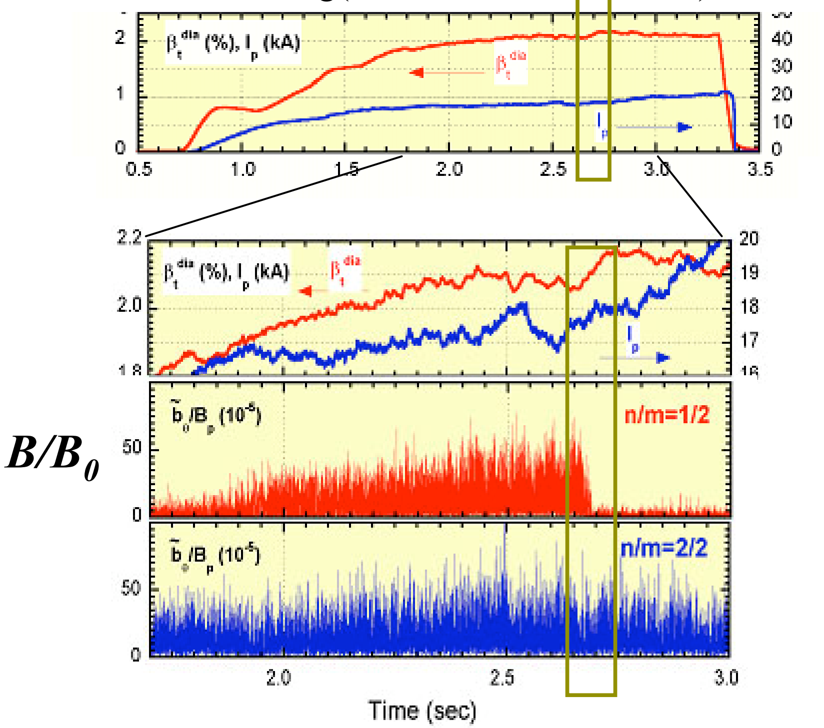
=> Possibility of Achievement in Stationary ????

Effects of resonant fluctuations on global confinemets in LHD

Disappearance of only core resonant flucuation

#16964

R_{ax}=3.6m, B=0.75T, H_2-gaspuff-only
NB-heating(Co2.1MW,Cntr0.9MW)

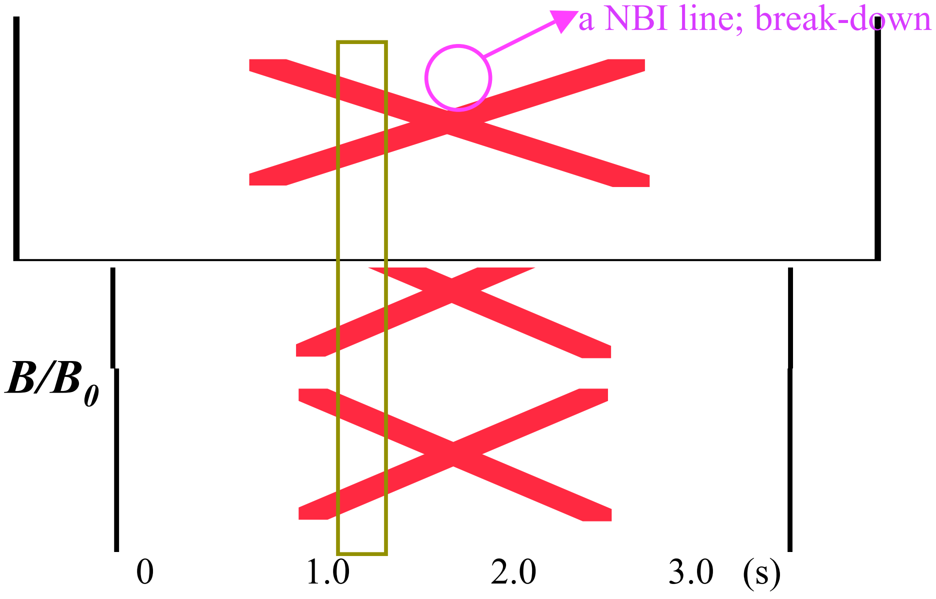


Impact on W_p ~5%

Disappearance of both core and edge resonant flucuations

#31811 *(more stability unfavorable conf. than 3.6m)*

R_{ax}=3.5m, B=0.5T, H_2-gaspuff-only
NB-heating(Co4.0MW,Cntr1.2MW)



After core resonant mode disappears,
peripheral resonant mode disappears

Impact on W_p ~30%

Core resonant fluctuation disappears because the resonant mag. surf. disappears due to toroidal current.

ST Systems

- SEEKS TO OPTIMIZE TOKAMAK THROUGH LOW A:

  HIGH BOOTSTRAP CURRENT
  LARGE FLOW VELOCITY & FLOW SHEAR
  LARGE MAGNETIC SHEAR
  LOW FIELD & LOW ALFVEN SPEED

- BRIDGES TOKAMAK PHYSICS BASE & TOOLS TO LOW A REGIME.

Rotation effects evident in n_e(R) profiles

- Most easily seen in MHD-quiescent L-mode discharges
- **Single-fluid MHD force balance:**

  $\mathbf{J} \times \mathbf{B} = \nabla p + \rho \mathbf{v} \bullet \nabla \mathbf{v}$ Þ

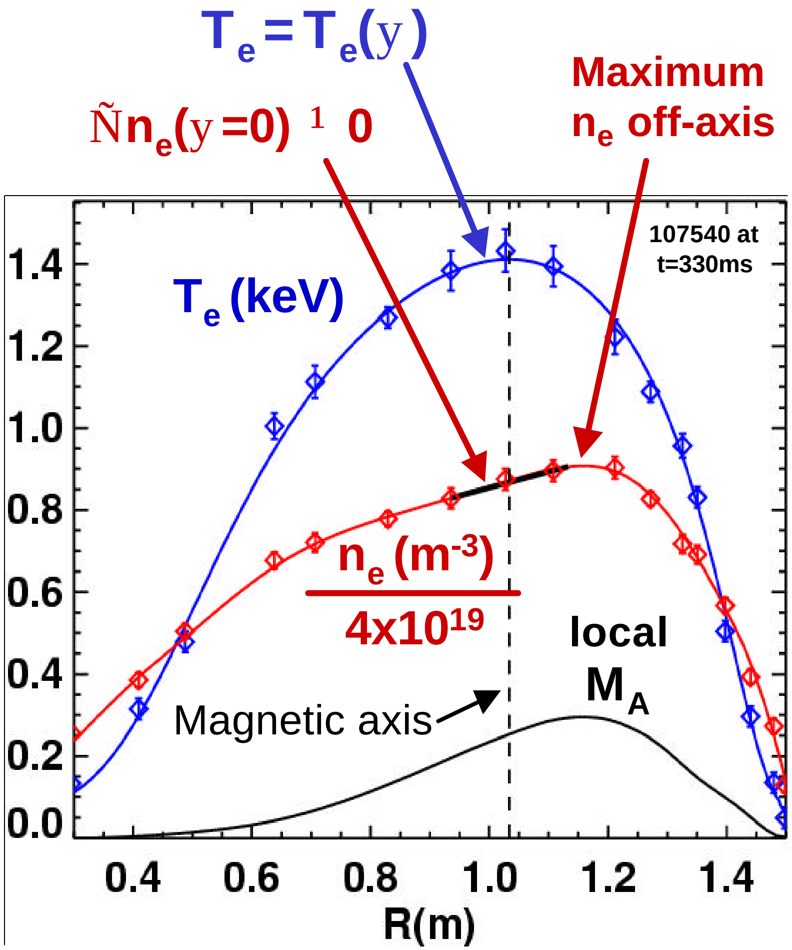
  - **Near axis**, **J** × **B** small ⇒

    $R/p\ \partial p/\partial R = M_S^2 = 2M_A^2 / \beta$

    $M_S \equiv v_\phi / v_{Sound}$

    $M_A \equiv v_\phi / v_{Alfven}$

- M_S = 0.4-0.7 ⇒
  - strong impact on equilibrium
    - Similar to standard tokamak
- M_A = 0.15-0.4 ⇒
  - strong impact on stability
    - **2-3 ´ larger than standard tokamak**



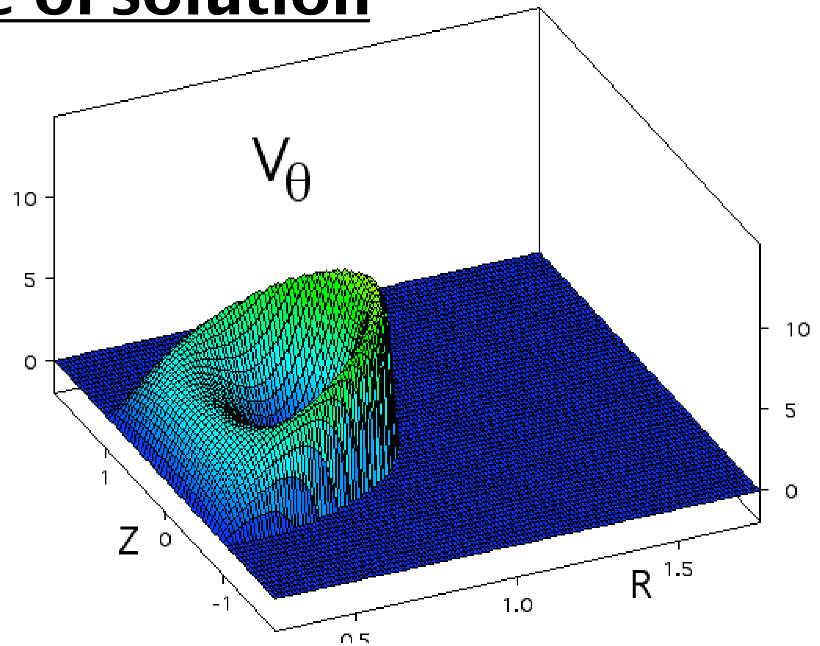
Numerical solution

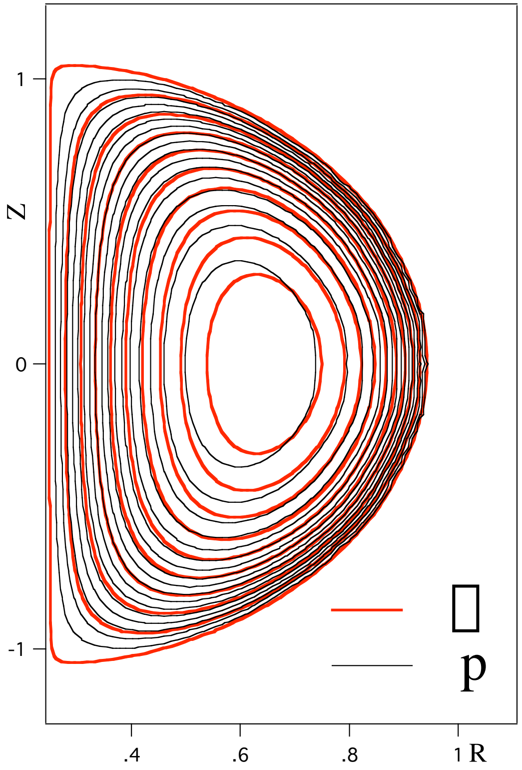
scheme

$$\begin{cases} \square^*\square = \square\dfrac{r^2}{|\square\square|^2}\left(p_z\square_z + p_r\square_r\right)\square FF\square\square\dfrac{r^3\square_r}{|\square\square|^2}f^2 & ● \\ p_r = \square\dfrac{\square_r}{r^2}\left(\square^*\square + FF\square\right)\square rf^2 \\ p_z = \square\dfrac{\square_z}{r^2}\left(\square^*\square + FF\square\right) \end{cases} \xrightarrow{\text{div}} \square p = \square\square \; ●$$

solve two(●) Poisson's eqs. simultaneously by iterations

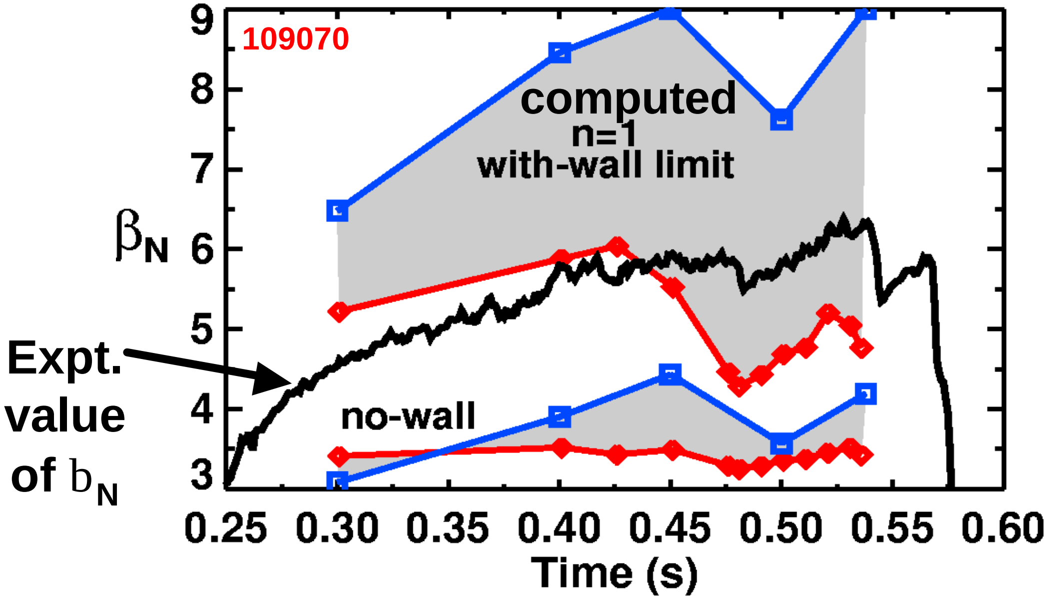
example of solution

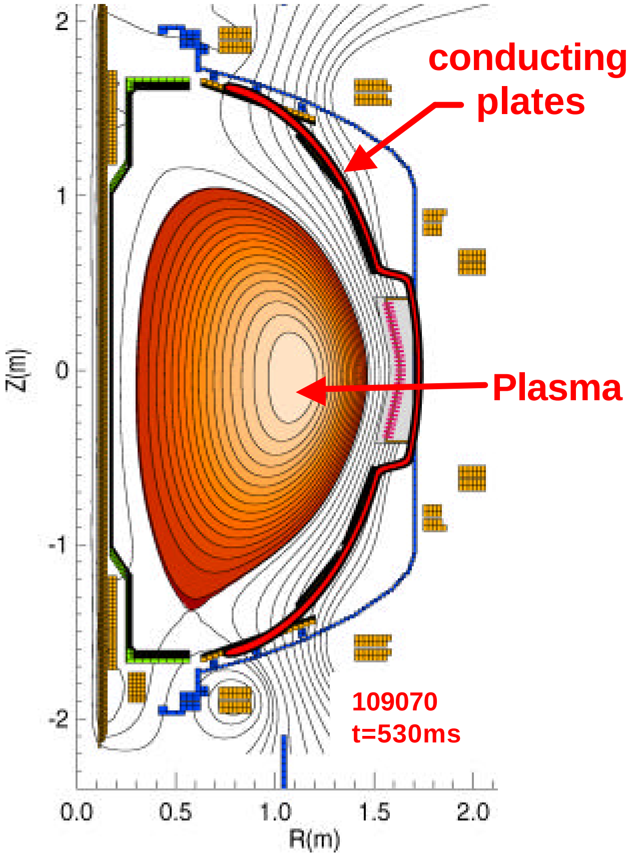




Elevated *q* sustains operation above no-wall limit

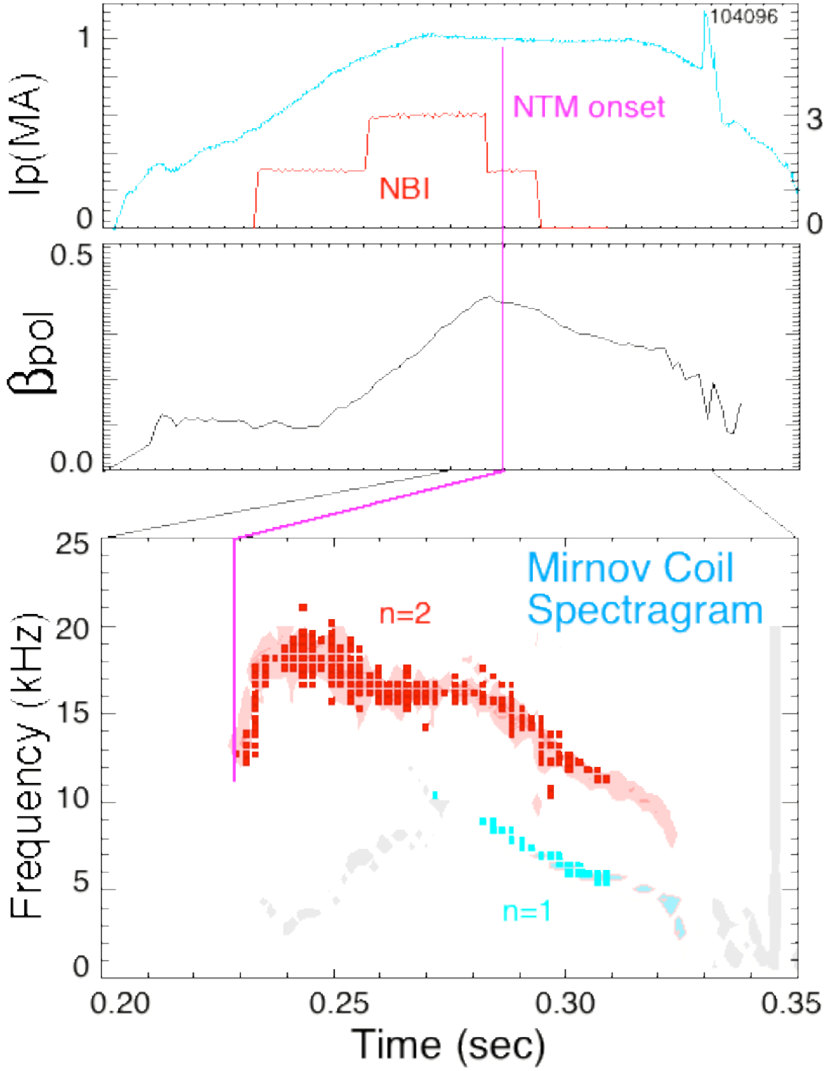
- Increase *q* the old-fashioned way:
  - Raise field from 0.3T to 0.5T + early H-mode
  - Decrease current to 0.8MA $\Rightarrow f_{BS} \rightarrow$ 50%
- Operate with $\beta_N > 5$ for $\Delta t > \tau_{CR}$=0.25s
  - **No rotation slow-down or evidence of RWM**





- Stabilization of RWM with rotation+dissipation demonstrated on DIII-D
- **Compare NSTX RWM predictions to DIII-D using MARS code**

NTMs seen in high performance NSTX discharges



- Roll-over in □ starts with beam power stepdown.
- No chirps, but beams off early in mode.
- Interestingly, no clear trigger, early large frequency jump.
- Accompanied later in time by core n=1 ideal mode

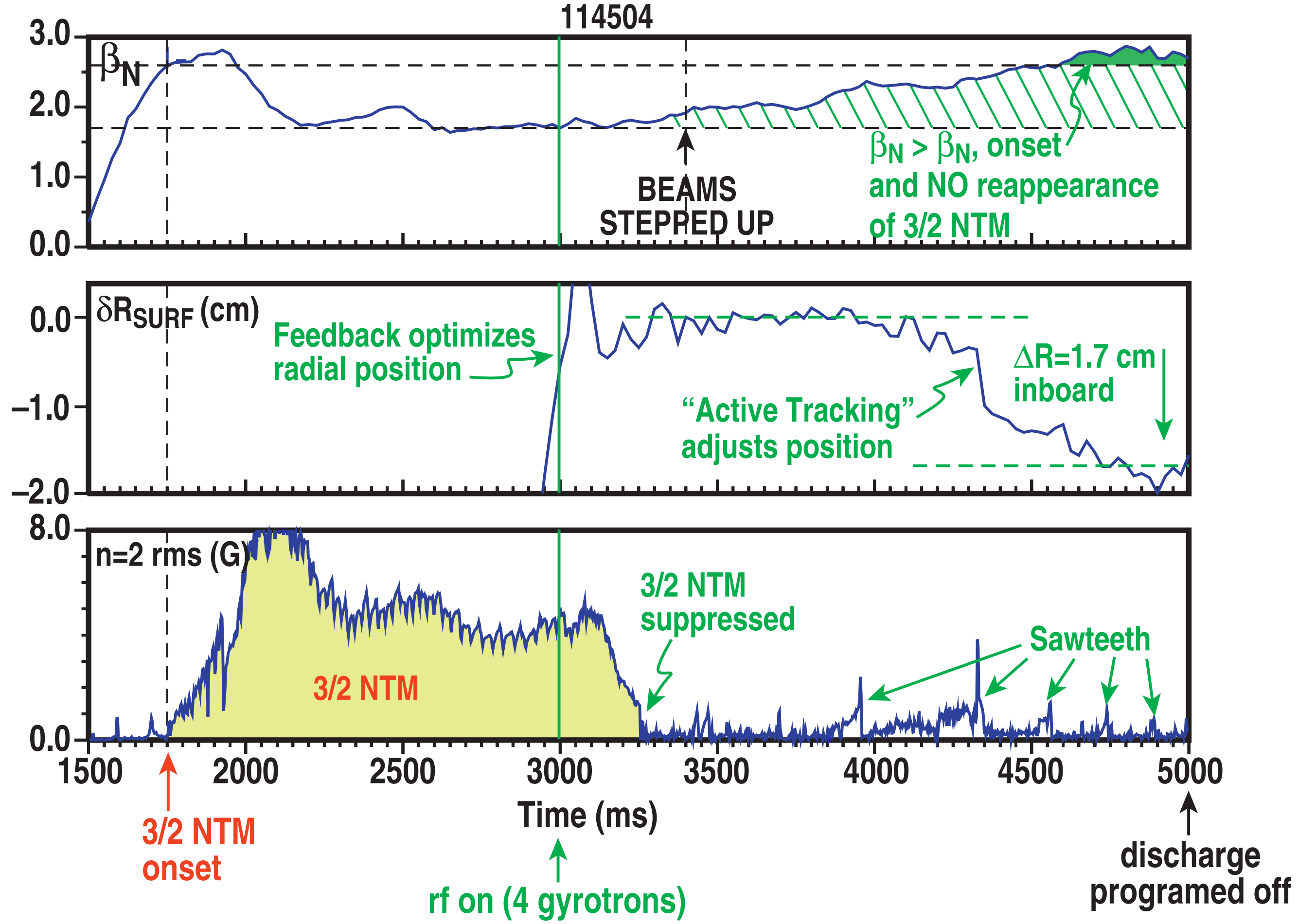
Tokamak Systems

- SEEKS TO OPTIMIZE TOKAMAK THROUGH CONTROL OF MHD:

  NTM
  RWM
  ELM

ACTIVE TRACKING OF RATIONAL SURFACE ALLOWS STABILITY ABOVE THE PREVIOUS NTM LIMIT

- Feedback system adjusts R_{SURF} to minimize mode amplitude (“search and suppress”)
- Active tracking keeps ECCD at the q=3/2 surface <u>in the absence of the mode</u>
  - Compensates for the Shafranov shift as beta increases
- Mode does not reappear when β is raised above the initial stability limit



BEAMS STEPPED UP

$\beta_N > \beta_N$, onset and NO reappearance of 3/2 NTM

Feedback optimizes radial position

“Active Tracking” adjusts position

ΔR=1.7 cm inboard

3/2 NTM suppressed

Sawteeth

3/2 NTM onset

rf on (4 gyrotrons)

discharge programed off

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

NTM growth and its stabilization by ECCD in JT-60U experiments

NTM island growth (E36705)

m/n=3/2 mode NTM grew from t=6.4 s and was saturated at t=7.2 s.

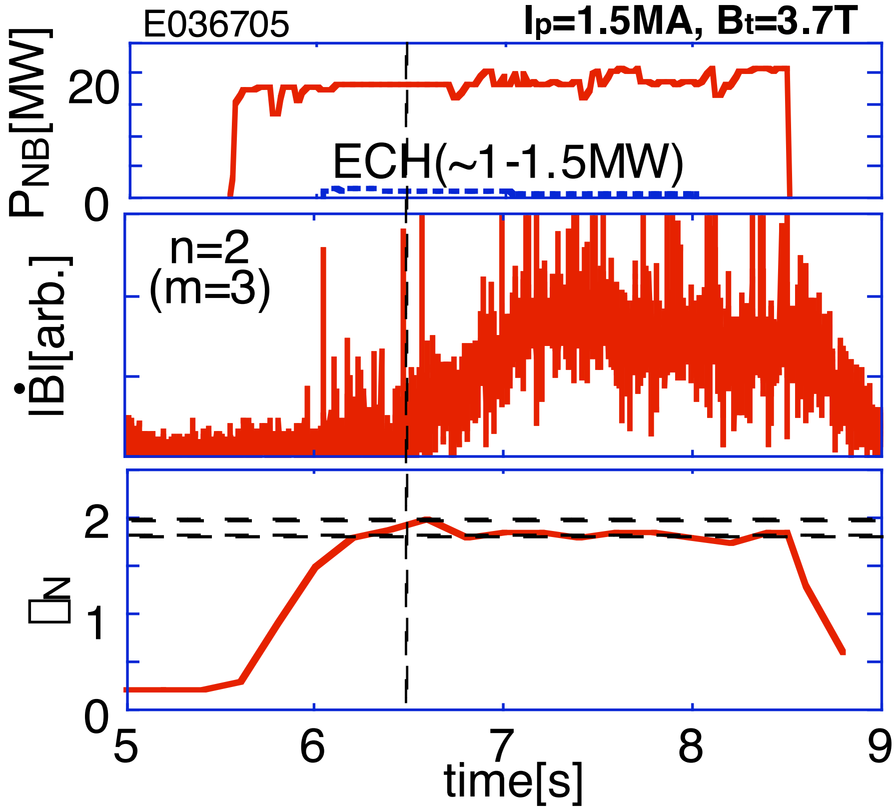
Normalized beta was decreased by about 10%.

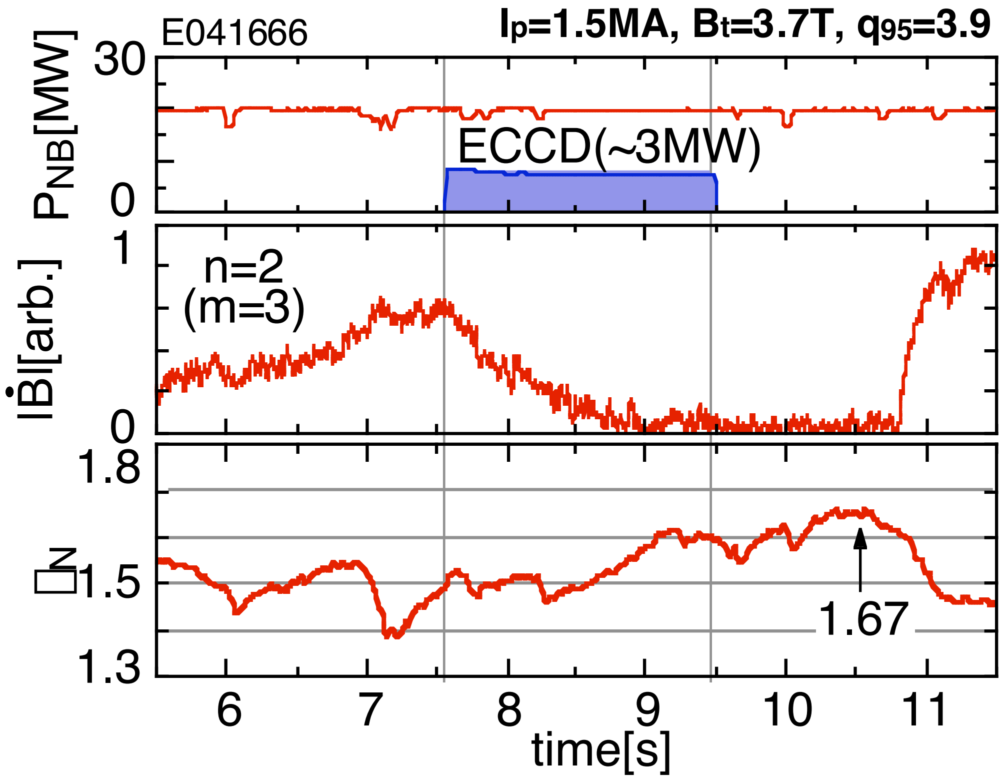
Stabilization by ECCD (E41666)

Fundamental O-mode EC wave of 110GHz was injected to 3/2 mode NTM.

Real-time control of the EC current location (island is detected from T_e perturbation) could completely stabilize the NTM.

A.Isayama, et al. 19th IAEA conf.





CONCLUSIONS FOR ITER

- Proposed 20 MW, 170 GHz, “high launch” system
  - ★ at best adequate to control either or both the 3/2 and 2/1 NTMs
  - ★ good alignment and modulation can keep both islands small

    . . . $P_{rf} \approx 16 + 10 \approx 26$ MW injected power

    — for –2% and –4% energy loss respectively

- Additional focusing and/or a lower launch should be investigated
  - ★ for a narrower, better matched current drive

    . . . requiring lower rf power

- A full sensitivity study on w_{marg}, δ_{ec} and $\Delta'r$ remains to be done

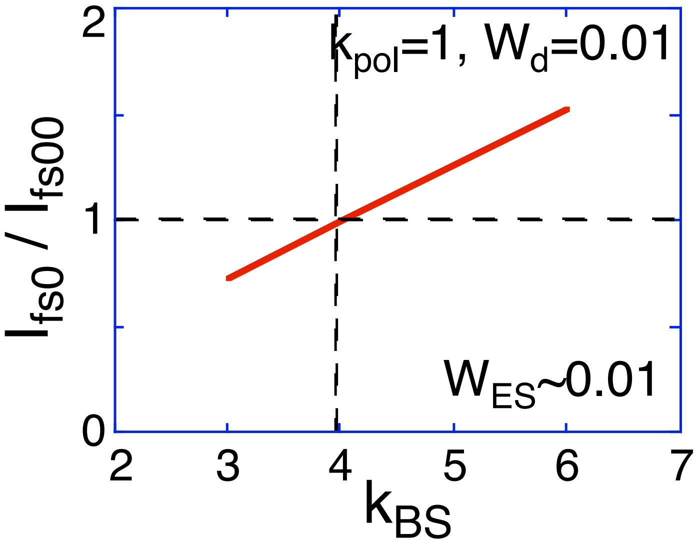
- Existing devices need to prove out modulation (ASDEX UPGRADE?)
  - ★ and prove out role of δ_{ec} on P_{rf} (DIII–D 2004)

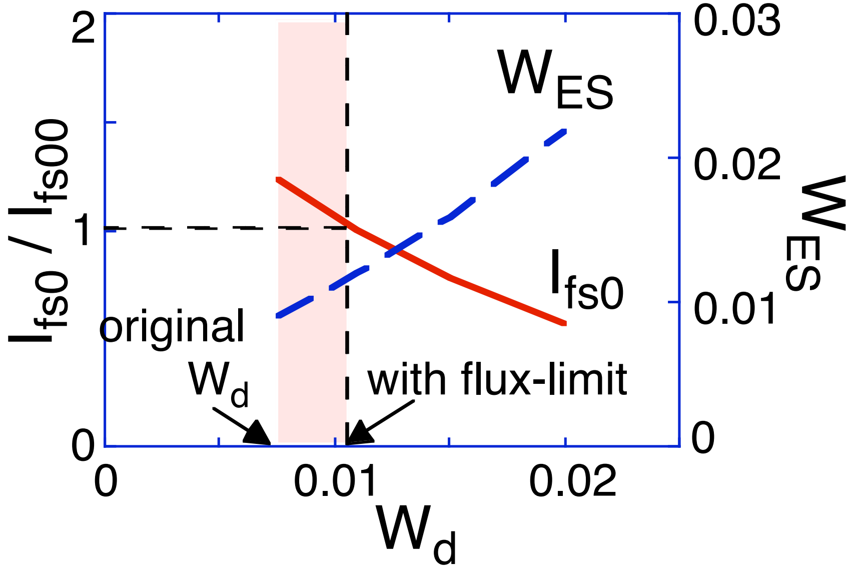
Necessary EC current much depends on the parameters of bootstrap current and ECCD terms in the modified Rutherford equation.

Dependence of I_{fs0} on k_{BS} and W_d is strong, while that on k_{pol} are rather weak.

Value of W_{ES} increases with W_d, while that is not much varied by k_{BS} and k_{pol}.

From modified Rutherford eq., $I_{fs0} \quad 1 / k_{EC}$





For k_{BS}~4, k_{pol}~1, k_{EC}~4, W_d~0.01 estimated from JT-60U experiment,

I_{fs0} ~ 74 kA for 3/2 mode and ~ 54 kA for 2/1 mode on ITER (error~20%) .

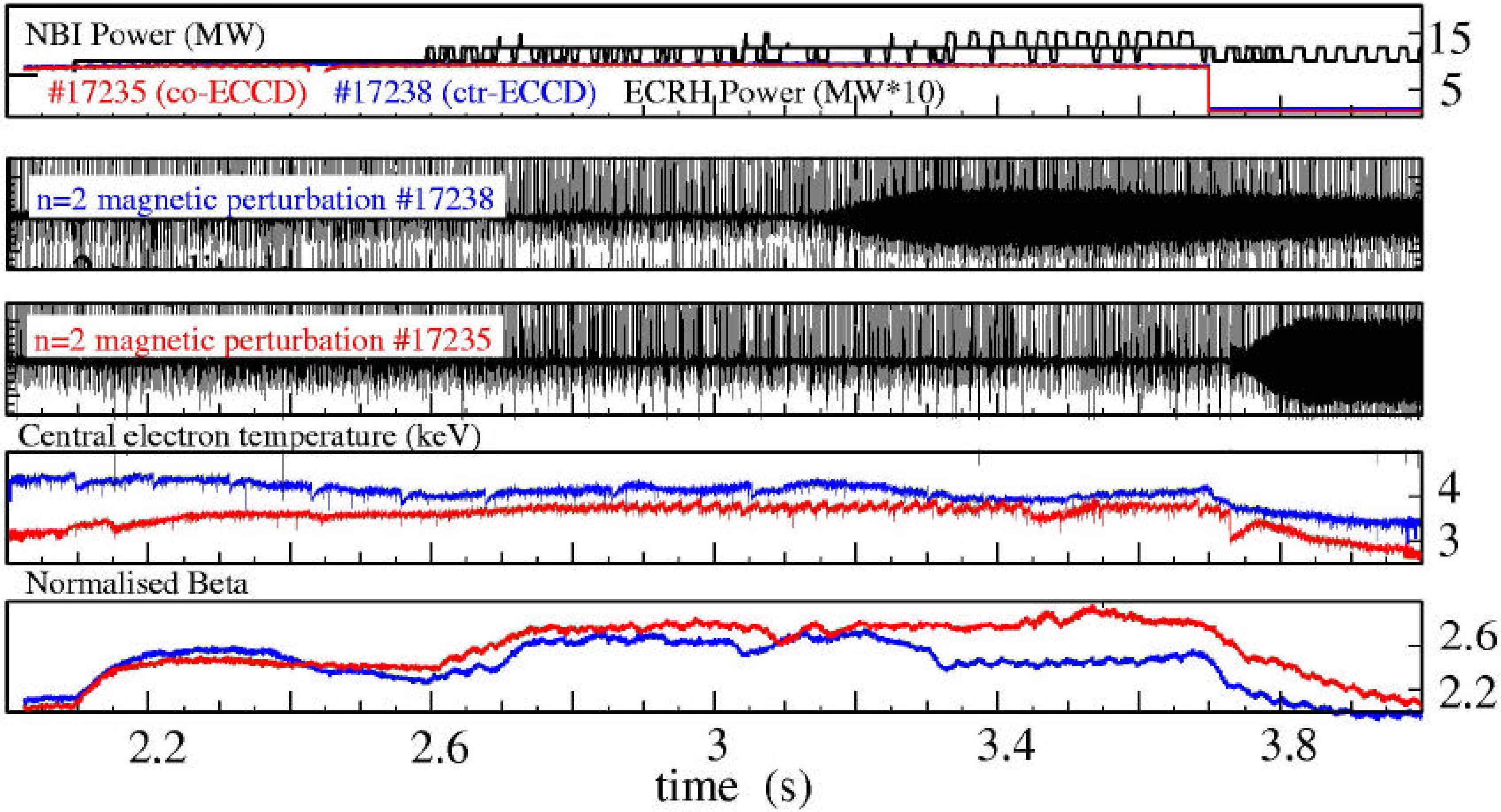
EC code results : P_{EC}(MW) ~ 0.23 I_{EC}(kA) for 3/2 mode
~ 0.24 I_{EC}(kA) for 2/1 mode

ECCD power necessary for both 3/2 and 2/1 modes NTM stabilization on ITER is 30 MW.

Necessary ECCD power can be reduced to 12 MW when the EC current width is half decreased by optimizing both toroidal and poloidal injection angles.

W_{ES}~0.01 (2 cm) is small for early stabilization.

NTM control by sawtooth mitigation (off-axis-ECCD)



Co –ECCD:

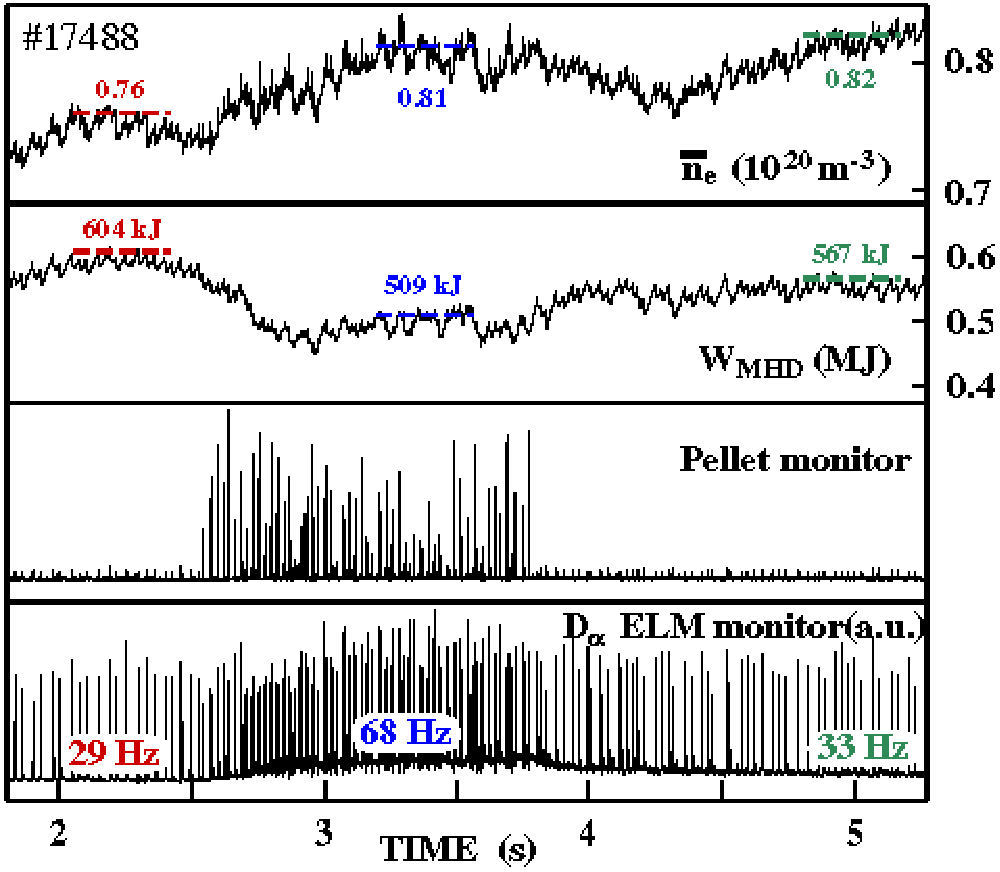
- no sawteeth as expected
- Reduced fishbone amplitude
- NTM triggered after ECCD (by ST)

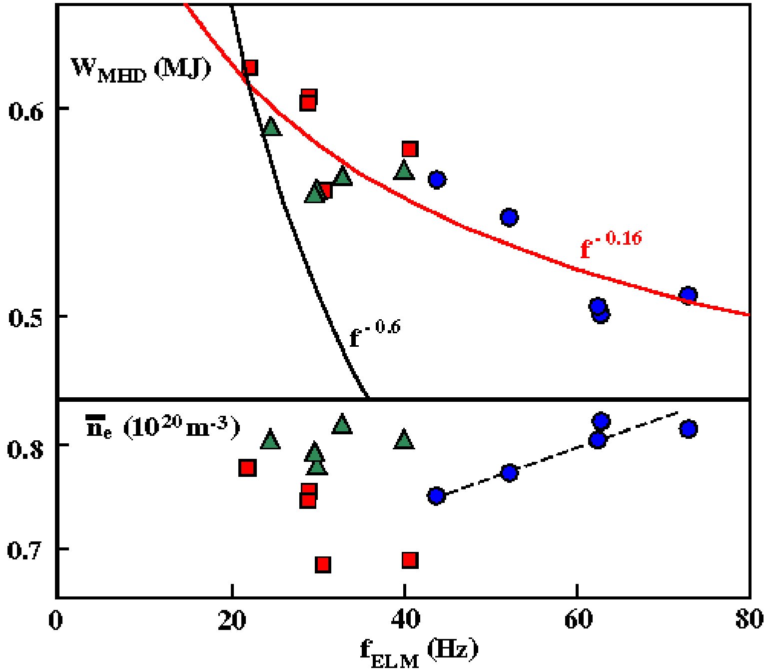
Counter-ECCD:

- NTM triggered by FB during ECCD

Control of ELM frequency by pellets

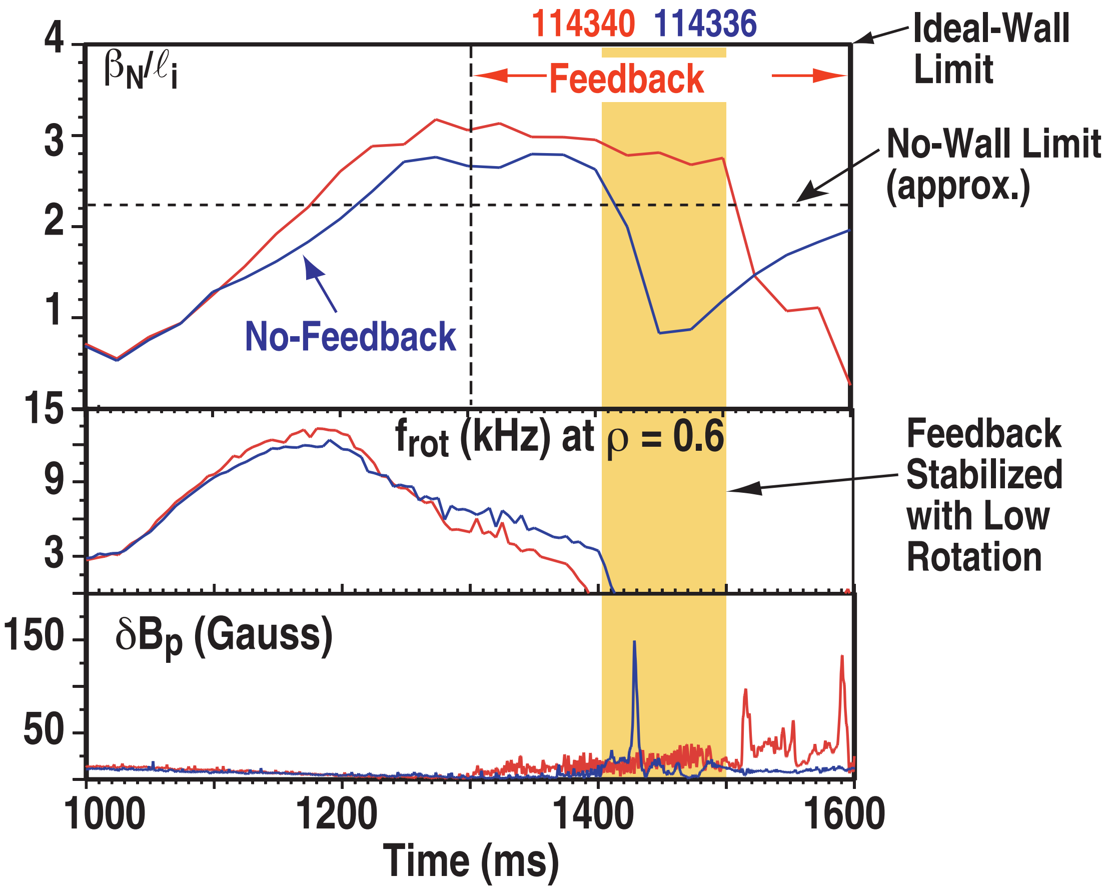
- small pellets (2 … 3x10^{19} D atoms, not strong fuelling)
- Confinement degradation ~ $f^{-0.16}$
  (less than for frequency change by, e.g., heating power or gas puff)

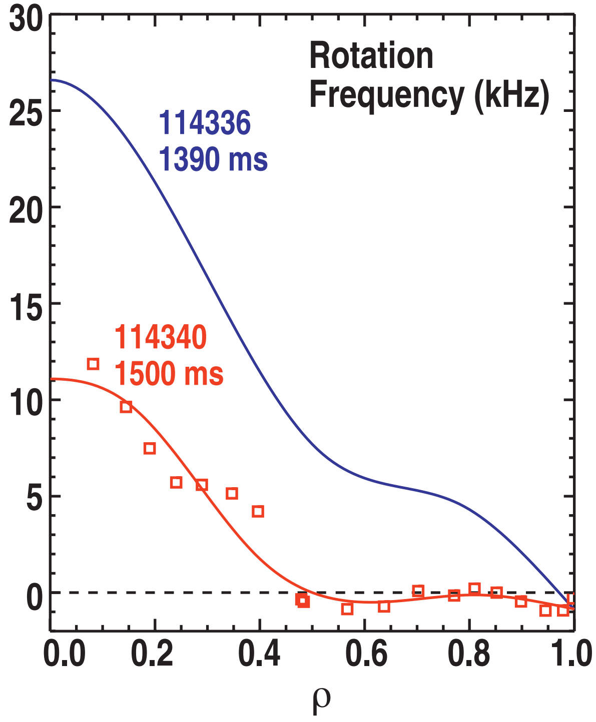




FEEDBACK CONTROL WITH INTERNAL COILS STABILIZES RWM WITH LOW ROTATION

- Magnetic braking reduces rotation to zero in the outer half of the plasma
- Feedback with internal coils maintains stability for >100 ms
- Case without feedback becomes unstable at lower beta, even with rotation



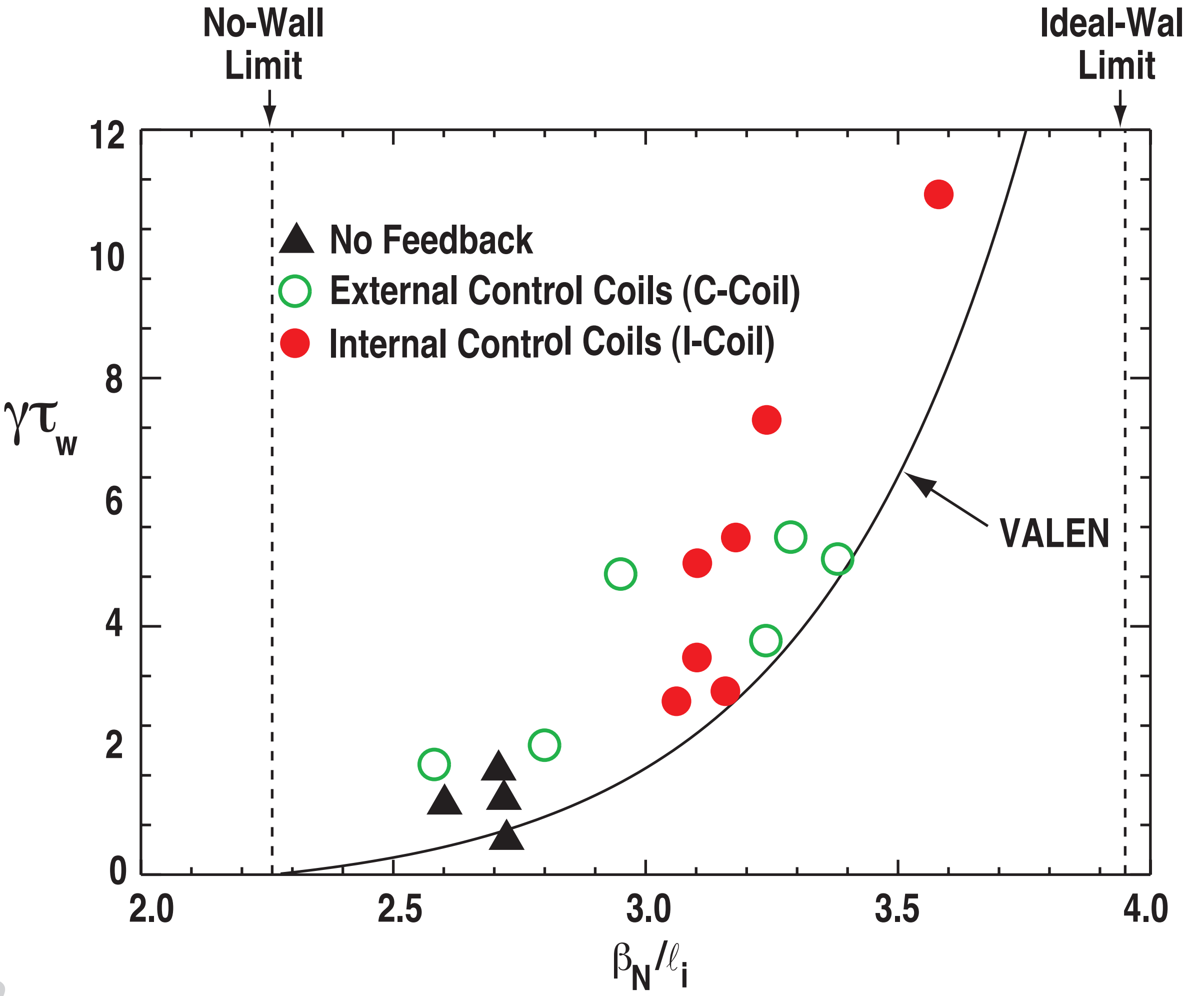


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

236-03/rs

FEEDBACK WITH I-COIL CAN CONTROL RWM GROWTH CLOSER TO THE IDEAL WALL LIMIT

- Observed growth rate of unstable RWM is consistent with VALEN calculation



238-03/rs

Comparison with Prior Scalings

LaHaye 1997 strong size scaling is contradicted by C-Mod

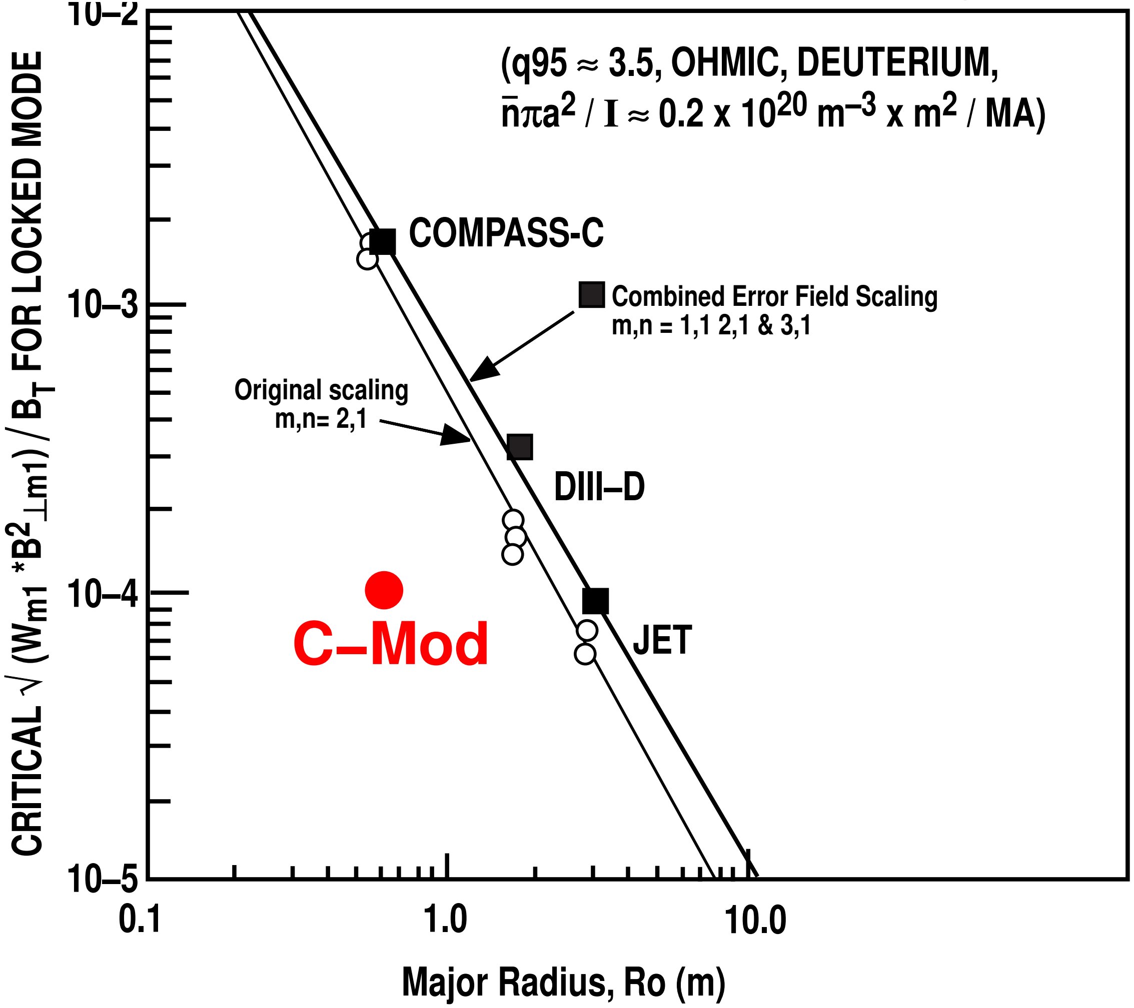
Scaling developed by comparing Compass/DIII-D/JET data.

Experimental scaling of threshold with size appeared very bad for ITER.

Supported by theory-based arguments for $B_{\mathrm{lock}} \propto R^{-9/5}$

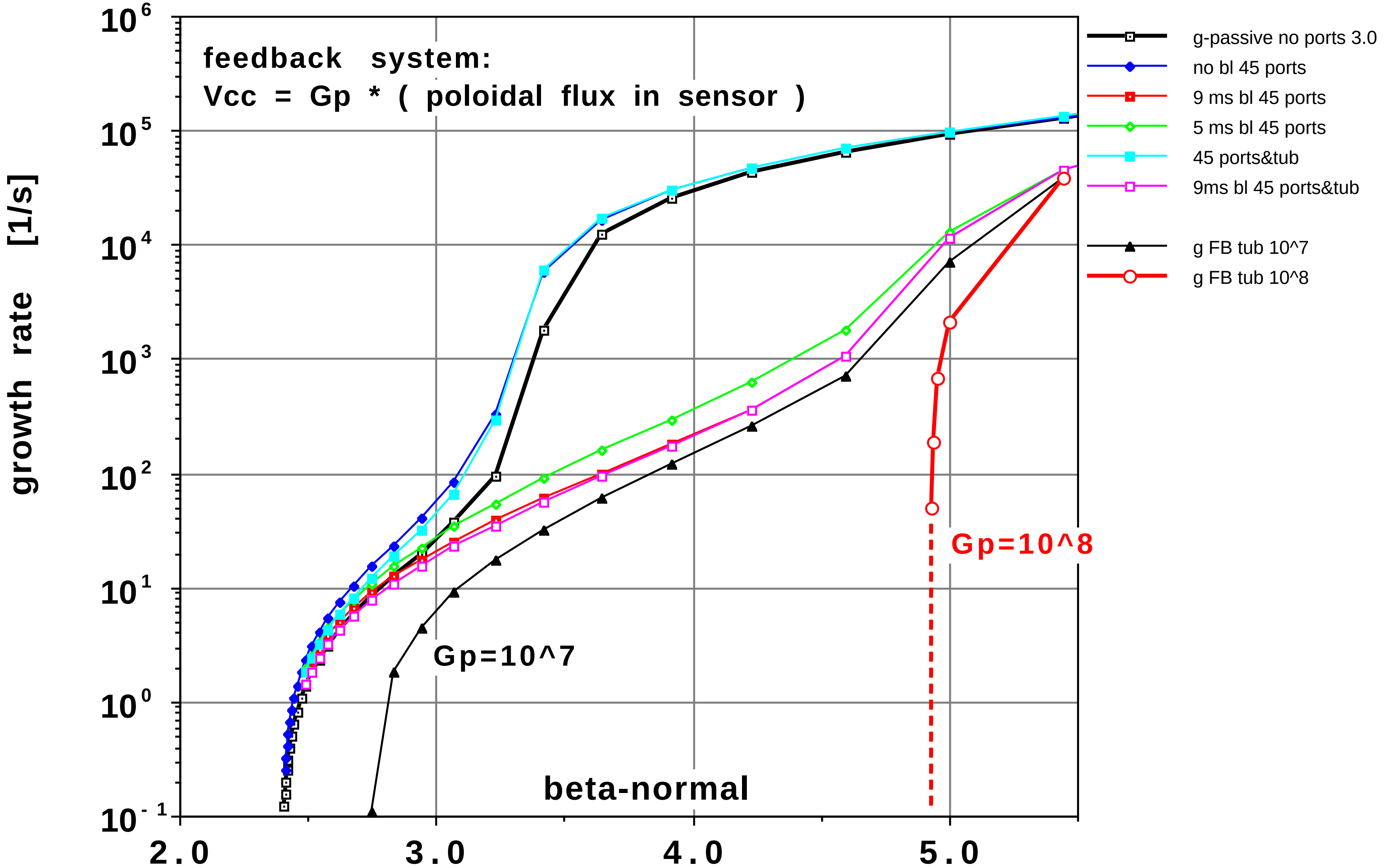
C-Mod locking threshold is factor > 10 below scaling, $\sim$ same fractional value as for DIII-D and JET.

Locking Threshold Scaling (LaHaye 97)



[Compass data different from others, has very strong inverse B_t scaling.]

VALEN Results for ITER
Feedback Performance With Internal Coils

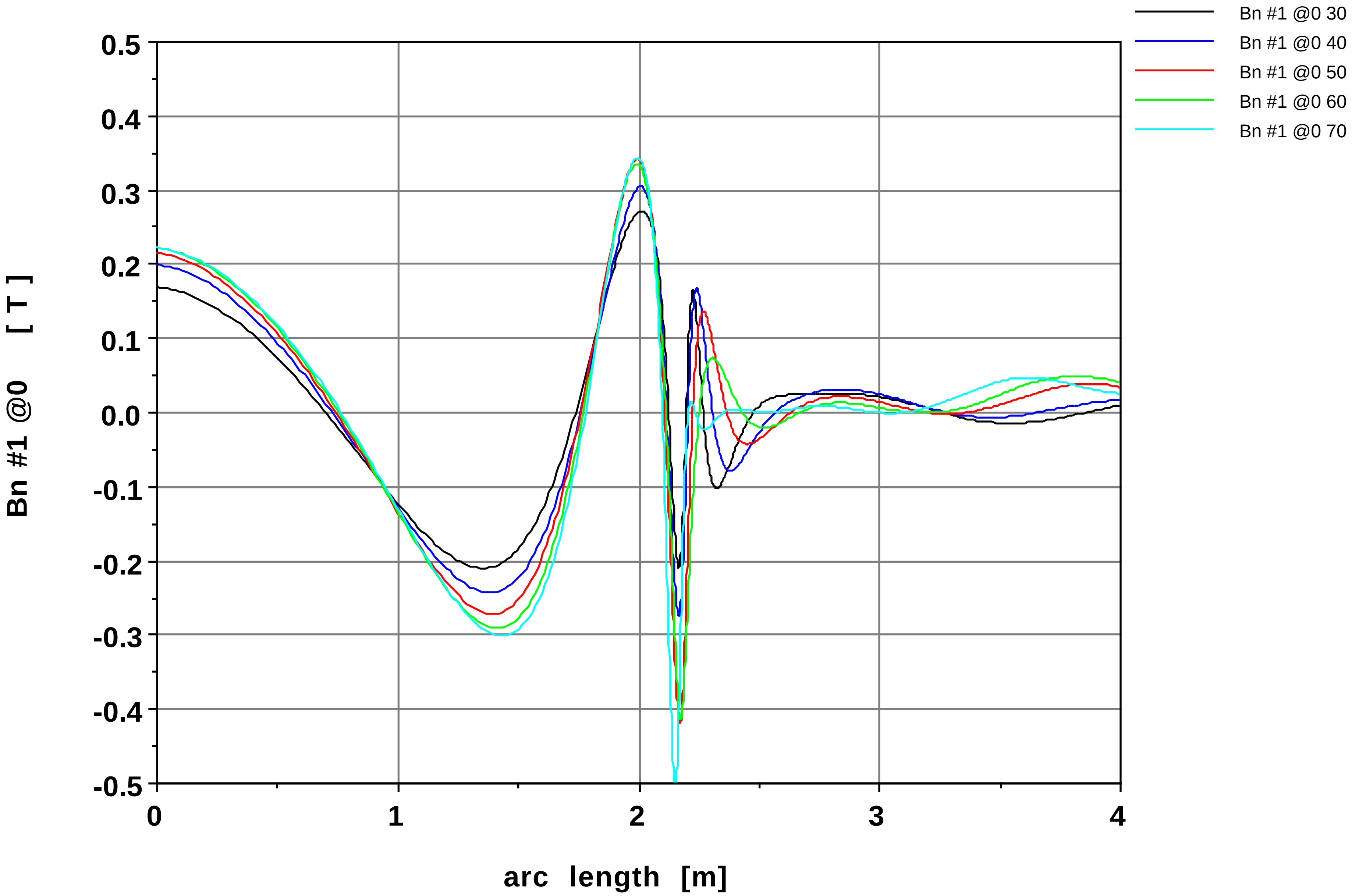


Data from "ITER.01.2004.w.betan"

SUMMARY / CONCLUSION

- For the n=0 RWM, it was shown that the plasma can deform in response to the feedback system, and this needs to be taken into account in the detailed design of a feedback system
- For the n=1 RWM, the plasma will also deform in response to the feedback system. For the NMA analysis, this is equivalent to keeping “stable” modes in the analysis of the unstable mode with feedback
- MARS should have this effect included and agrees with NMA in benchmarking
- VALEN does not include this effect; there should be a detailed comparison between VALEN and NMA/MARS to assess the importance for ITER

SMALL VARIATION IN MODE WITH BETA



We need the definitions to start the benchmarking

$$s = \frac{-\delta W}{\left(LI^2/2\right)}$$	➢ What is L ? ➢ What is I ?

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s is not a generally accepted parameter.
However, it plays important role in the theory used in VALEN code:

A. H. Boozer, Phys. Plasmas 5, 3350 (1998).

A. H. Boozer, Phys. Plasmas 6, 831 (1999).

A. H. Boozer, Phys. Plasmas 6, 3180 (1999).

J. Bialek, A. H. Boozer, M. E. Mauel, and G. Navratil, Phys. Plasmas 8, 2170 (2001).

A. H. Boozer, Phys. Rev. Lett. 86, 5059 (2001).

A. H. Boozer, Phys. Plasmas 10, 1458 (2003).

A. H. Boozer, Phys. Plasmas 11, 110 (2004).
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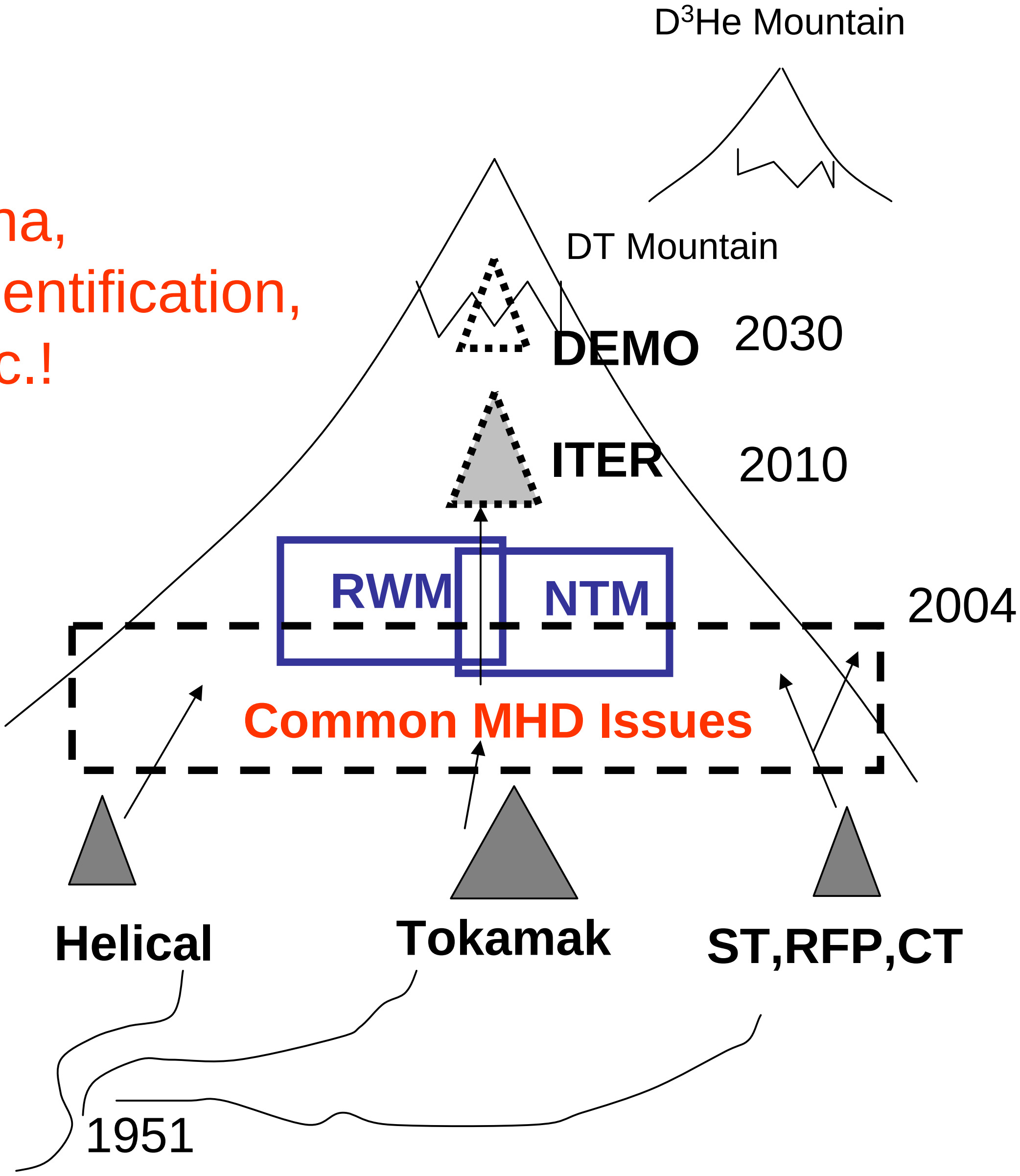
Clarify
  Common Phenomena,
  Common Physics Identification,
  Common Scaling etc.!



Summary of Large Tokamak workshop on “Physics of Current Hole” (W56)
JAERI Naka, Japan Feb. 3-4, 2004.

- **Equilibrium**
  - **m=1or2/n=0 islands (Martynov), m=2/n=0 islands (Takizuka)**
  - **Complete j(0)=0 equilibrium (Chu)**
  - **3D-code; iota=0 in helical systems (Kanno), tokamak eq. w. VMEC (IPP-Garching)**
  - **BS current in a current hole (Chankin)**

- **Stability and sustainment mechanism**
  - **Axi-symmetric event (Huysmans)**
  - **Finite beta effect (Jardin)**
  - **In above two, stationary state with flow is realized for limited conditions.**
  - **Radial flow with NB (Jensen)**

- **Transport simulation**
  - **Oscillatory behavior in q(r) and p(r) (TSC, Nakamura)**
  - **Neoclassical ITB + CH (TOPICS, Hayashi)**

- **Experiment**

  JET; LFS-localized beam ions, off-axis sawtooth
  JT-60; current clamp for positive/negative CD, less stiff Te(r)
  AUG; CH in NB ion ITB and on-axis ctr-ECCD
  LHD; zero iota with counter NBCD, off-axis peak in Te.
  DIII-D; NCS->CH, EFIT and MSE improved, RWM study.

- **Reactor application and related studies**

  Is CH generated ITER? -> Scaling for formation conditions from multi machine experiments.

  Confinement of alpha/NNB particles, MHD/AE stability, Controllability, Impurity accumulation, Transport scaling, ...

- **Future directions in physical studies**

  Neoclassical theory in CH (bootstrap, conductivity (σ, χ), ...)

  Nonlinear MHD simulation for more relevant to experiments.

  Can experiments be reproduced with MHD simulation only or is transport modeling also needed?

  What can be done in experiments? (local heating, 2D camera diagnostic, more accurate Bp/Te/Vp measurements,fluctuation measurements, ...)

ITPAにおける課題

緊急で重要度の高いもの

- **NTM 低ベータでのベータ値向上を制限するものとして**
  1. NTMによる磁気島の安定化と高ベータ化へ（主にECCDによる）
  2. NTMの発生機構と制御（Sawteethや誤差磁場等による発生とその制御）
  3. NTMの理論モデルと実験的検証
  4. ITERでのNTMの制御シナリオ、制御システムへの要求

- **RWM 高ベータ達成への障害として**
  1. RWM安定化の実験と理論モデル
  2. RWM安定化への回転、誤差磁場等の影響
  3. ITERでのRWMの予測と、制御システムへの要求

- **ディスラプション 回避すべき対象として**
  1. ディスラプションデータベース（負磁気シアプラズマを含む）
  2. キラーペレット、ガスジェット入射等によるディスラプション緩和技術開発（ハロー電流、逃走電子抑制、制御を含む）

CHAPTER 3
MHD STABILITY, OPERATIONAL LIMITS AND DISRUPTIONS

TABLE OF CONTENTS

Participants of the fourth ITPA meeting on MHD, Disruption and Control are marked in red.

3. MHD STABILITY, OPERATIONAL LIMITS AND DISRUPTIONS

90 pages of A4 format (in IPB it was 254)

- proposed authors by the TG on M,D&C are listed;
- proposed leading authors are underlined;
- listed authors, who have not yet agreed, are put in green.

3.1. INTRODUCTION **2-3 pages**

(Including summary of the results from ITER Physics Basis : chapter 2.1 Ideal MHD Stability limits and chapter 3.1 Disruptive Density Limits ; organization of this chapter)

O.Gruber, E.Strait, T.Ozeki

3.2. MHD STABILITY

3.2.1. Sawtooth Oscillations

(Note: the section on fishbones is removed from chapter 3 to chapter 5, not yet negotiated)

3.2.1.1. Physics of sawtooth oscillations 2 pages

L.Zakharov, F.Porcelli, O.Sauter

(Note: the effect of fast particles on sawteeth will be treated in this section)

3.2.1.2. Control of sawtooth oscillations *(ECRF, ICRF, NI)* 4 pages

T. Goodman, E.Westerhof, A.Isayama, O.Sauter, H.Zohm

3.2.1.3. Central MHD activity expected in ITER and their control 2 page

S.Jardin, G.Pereverzev, B.Goodmann, L.Zakharov

3.2.2. Neoclassical Tearing Modes

3.2.2.1. Physics of NTMs *(including thresholds and power ramp-down)* 3 pages
O. Sauter, C.Hegna, T. Ozeki, S. Günter, R. Buttery, H.Wilson, S.Jardin
3.2.2.2. Active Control of NTMs 4 pages
H. Zohm, A.Isayama, R.. LaHaye, R.Buttery
3.2.2.3. Mitigation of NTMs *(sawtooth suppression, FIR mode)* 4 pages
S. Günter, O.Sauter,
3.2.2.4. NTMs expected in ITER and their control 2-3 pages
R. LaHaye, G. Giruzzi, S. Günter, A.Zvonkov, B.Lloyd, A.Popov N.Hayashi

3.2.3. Resistive Wall Modes

3.2.3.1. Physics of RWMs *(includ. role of rotation and error fields)* 4 pages
A.Bondeson, E.Strait, G.Navratil, A.Garofalo, T.Hender, M..Takechi, A.Boozer
3.2.3.2. Control of RWMs 4 pages
E.Strait, G.Navratil, M.Okabayashi, V.Pustovitov
3.2.3.3. RWM expected in ITER and their control 3 pages
Y.Gribov, A.Bondeson, G.Navratil, V.Pustovitov

3.2.4. Physics of ELMs: Edge Stability

H.Wilson, G.Huysmans, Snyder, L.Lao, L.Horton, S.Günter, T.Oikawa, L.Villard
3.2.4.1. Edge stability *(types I,II,III ELMs)* ≤5 pages
3.2.4.2. Expectation for ITER 1-2 pages
(Active control of ELMs via pellets, edge currents, . in Section 5)

3.2.5. Error Fields

3.2.5.1. Effect of error fields on plasma *(locked modes, NTMs, RWM: see 3.2.3.1)* 3 pages
T.Hender, R.Buttery, R. LaHaye, R.Fitzpatrick, E.Lazzaro, Sato
3.2.5.2. Error fields expected in ITER and their correction 2 pages
Y.Gribov, T. Hender

3.2.6. MHD Stability in Advanced Scenarios

3.2.6.1. MHD stability in plasmas with weak magnetic shear *(q_0°= 1°-°2)* 2 pages
J. Manickam, E.Strait, T.Ozeki, G.Huysmans

3.2.6.2 MHD stability in plasmas with strong negative magnetic shear *(q_{min}°= 1.5 —2.5)* 4p.
T.Ozeki, S.Jardin, A.Turnbull, C.Kessel, H.Zohm, T.Hender

3.2.6.3. Expectations for ITER 2 pages
S.Medvedev, C.Kessel, T.Ozeki, J. Manickam

3.2.7. Summary **2-3 pages**

E.Strait, H.Zohm, T.Hender, T.Ozeki

3.3. DISRUPTIONS

O.Gruber, M.Sugihara, R.Granetz, Y.Kawano

3.3.1 Disruption Characterization **3-4 pages**

(causes and mechanisms, major disruptions and connected vertical displacements, disruptions due to vertical instability VDE , thermal and current quenches, neutral point , waveform of plasma current)
V.Riccardo, M.Sugihara, R.Granetz, Y.Nakamura (neutral point), G.Pautasso, S.Mirnov, A.Hyatt, D.Gates

3.3.2 Thermal Loads **4 pages**

G.Pautasso, G.Federici, D.Whyte, N.Asakura, P.Andrew

3.3.2.1. Thermal loads during thermal quench
3.3.2.2. Thermal loads during current quench
3.3.2.3. Expectation for ITER

3.3.3 Halo Currents and Mechanical Forces **2 pages**

(asymmetries, vertical / radial forces)
R.Granetz, Y.Kawano, D.Humphreys, G.Pautasso, V.Riccardo

3.3.3.1. Major disruptions
3.3.3.2. VDEs
3.3.3.3. Expectation for ITER *(in fact, results of the simulations (ch. 3.3.5) will enter)*

3.3.4. Runaway Electrons Generated by Disruptions **3 pages**

Y.Kawano, V.Riccardo, D.Humphreys, P.Helander

3.3.4.1. Generation of runaway electrons
3.3.4.2. Interaction of runaway electrons with plasma facing components
3.3.4.3 Mitigation of runaway electrons
3.3.4.4 Expectation for ITER

3.3.5. Simulations of Disruptions in ITER **3-4 pages**

M.Sugihara, S.Jardin, V.Lukash, Y.Nakamura

3.3.5.1 ITER disruption simulations *(disruption guidelines, simulator)*
3.3.5.2 Predictions for major disruption
3.3.5.3 Predictions for VDEs

3.3.6. Disruption Avoidance, Prediction and Mitigation

3.3.6.1. Disruption predictions *(locked modes, neural nets,..)* 3 pages
P.Sonato, G.Pautasso R.Yoshino, Lewer
3.3.6.2. Disruption avoidance 3 pages
V. Mertens, E.Strait, A.Kellman R.Yoshino, V.Riccardo
3.3.6.3. Disruption mitigation *(impurity killer pellets and gas puffs)* 4 pages
D.Humphrey, D.Whyte, G.Pautasso, Y.Kawano, P.Andrew
3.3.6.4. Disruption mitigation schemes for ITER 2 pages
D.Whyte, M.Sugihara

3.3.7 Summary **2 pages**

O.Gruber, M.Sugihara, R.Granetz, Y.Kawano

References **3 pages**

CHAPTER 8
PLASMA OPERATION AND CONTROL

TABLE OF CONTENTS

8. PLASMA OPERATION AND CONTROL

30 pages of A4 format (in IPB it was 73)

8.1. INTRODUCTION 2 pages

(Schemes and architecture for ITER plasma control, ITER Design Scenarios, organization of this chapter)

Y. Gribov, J.Lister, D.Humphreys

8.2. SURFACE AND WALL CONDITIONING 2-3 pages

(This section will be written by the Topical Group on Scrape-off-layer and Divertor Physics)

8.2.1. Conditioning Methods in Present Tokamaks

8.2.2. Conditioning Methods in ITER

8.3. PLASMA INITIATION

8.3.1. Plasma Initiation in Present Tokamaks 2 pages

(New results, e.g. EC assisted plasma initiation in low electrical field at JT-60U)

E. Lazarus, T.Fujii

8.3.2. Plasma Initiation in ITER 2 pages

Y. Gribov, A.Portone

8.4. PLASMA BASIC CONTROL

8.4.1. Magnetic Position and Configuration Control

8.4.1.1. Magnetic control in present tokamaks 3 pages

(New results, e.g. experiments of magnetic control at TCV and there simulations with DINA, high triangularity control, shape identification methods.)

J.Lister, J.Ferron, W. Treutterer, K.Kurihara, F.Sartori

8.4.1.2. Magnetic control in ITER 3 pages

Y. Gribov, A.Portone, K.Kurihara, J. Lister

8.4.2. Plasma Performance Control

8.4.2.1. Performance control in present tokamaks 3 pages

(Control of ITB will be presented in Chapter˚6, control of ELMs will be presented in Chapter˚4.)

A.C. Sips, J.Ferron, D.Mazon, S.Ide, Joffrin

8.4.2.2. Performance and burn control in ITER 2 pages

M.Shimada

8.4.3. Plasma control simulations in present tokamaks and ITER 5 pages

(e.g. equilibrium, performance, analog to a flight simulator)

J.Lister, Y.Gribov, D.Humphreys, A.Portone, W. Suttrop

8.5. SUMMARY **2-3 pages**

J.Lister, Y.Gribov, T.Ozeki, D.Humphreys

References **3 pages**

Tokamak Physics Basisの執筆に関する議論

進行役O.Gruber(IPP)の議事進行は巧かった

- 上記、ITPAの課題を対象とした構成で章立てがされている
- 概ね、各節は、多国間の研究者の共著による

調整された点

- 他の部分との重複、矛盾した結論を避ける
- 議論のベースとなっている理論モデルが確立されたものかどうか議論の的となった
  1st publication は避ける（例　3.2.1.3でのPorcelliの内部キンクモデル）
- RWMの補正コイルによる制御に関する提案に対しては議論百出
  （例　3.2.3.3での側面補正コイルによる制御、磁気プローブの信号（ノイズを含む）に基づく）
- ITERの運転、制御に関しては、議論百出

議論における注目点-1

疑問点

- **LHDはトカマク研究者にとって何なのか**
  - LHDの研究者は、トカマク研究者に何をアッピールしようとしているのか
  - トカマク研究者は、非軸対称系も含めたトーラス系を念頭に置いているか
- **トカマクの電流ホール領域をMHDで記述できる ”集団運動 ”領域と考えて良いのか**
  - **磁気面が、温度、密度の良いリファレンスではない**
  - **磁気面が、粒子軌道の良いリファレンスではない**
  - **”個別運動 ”領域ではないのか**
- **新古典テアリングモード（NTM）の理論モデルは確立しているのか**
  - **アジャスタブルパラメータの存在**
- **抵抗性壁モード（RWM）の理論モデルは確立しているのか**
  - **定式化に現れるパラメータの定義の曖昧さ**

議論における注目点-2

個人的感想

- トーラス系のMHD平衡
  MHD平衡の多様性（トカマク電流ホール、LHDゼロ回転変換、LHDダブレット配位）
  3次元系のコードが2次元系で使用され始めている（VMEC2000）
- トーラス系の理論モデル、コード
  可能な限り、3次元系をベースとして理論モデル、コードを作成する
  多様な装置での同一テーマの比較研究
  NTM,RWM等の理論モデルを確立する
- LHD実験結果と理論の比較を理論モデルの検証、拡張へと利用する

物理サブクラスターの活動に関して

初日の夜、物理サブクラスターの活動に関して話し合いを持った。

- **様々な立場**
- **ITER研究支援に対する意識の違い**
- **問題意識を共有できるか**

活動への準備

- H16年度のLHD共同研究（研究会）へ申請「トロイダルプラズマのMHD安定性に関連した諸問題」
  代表：中島徳嘉
- 申請が承認されれば、物理サブクラスター活動のための研究会を開く
- 大学、JAERI、NIFS間の連係が取れるかどうかがポイント
- 大学、研究所の法人化の動きのなかで、共同研究の意味を考え直す