International Tokamak Physics Activity (ITPA)

A paradigm for international collaboration in science

by

R.D. Stambaugh
Chair, ITPA Coordinating Committee

American Association for the Advancement of Science
Annual Meeting

Boston, MA

February 16, 2008

International Tokamak Physics Activity (ITPA)

Origin

- ITPA was formed by four parties (EU, Japan, Russia, US)
  - Tokamak physics toward burning plasmas
  - Broader tokamak participation
  - Connection to stellarator community
- Formed with the endorsement of the IFRC and the FPCC
- Now Includes all 7 ITER members (EU, Japan, Russia, US, Korea, China, India)

Charter

Agreed principles for conducting the International Tokamak Physics Activity (ITPA)

September 3, 2001 Coordinating Committee

The International Tokamak Physics Activity (ITPA) aims at cooperation in development of the physics basis for burning tokamak plasmas. …….achievement of a broad physics basis useful for all fusion programs, for the ITER design, and for general tokamak research worldwide.

The ITPA shall consist in providing:

- **Validated experimental data according to an agreed format;**
- **Analyzed results of experiments to advance understanding of fusion plasma physics;**
- **The organization, management, and updating of qualified databases;**
- **Theoretical models and simulation results to explain and reproduce experimental results;**
- **Studies of fusion plasma performance in burning plasma tokamak devices, such as ITER; and**
- **Identification and resolution of key diagnostics issues which might arise both in plasma control and in analysis of a burning plasma experiment, such as ITER.**

Organizational Structure

- The ITPA organization includes a Coordinating Committee and seven Topical Physics Groups. While the membership of these international Topical Groups is limited to 5 from each party in order to maintain a continuity and coherence, the meetings are open to other scientists also.

- Management support is provided by the ITER International Team

ITPA Membership - June 2007

Members of ITPA Topical Physics Groups

	EU	JA	RF	US	CN	KO	IN	IT
Coordinating Committee	J Pamela† F Romanelli H Zohm	Y Nakamura† Y Kamada† S Takamura	N Ivanov† S Konovalov S Mirnov	E Oktay† N Sauthoff R Stambaugh*	Yuping Huo Jiangang Li† Chuanhong Pan	M. Kwon† J. H. Han Y. S. Hwang	P K Kaw Y C Saxena R Singh†	V Chuyanov D Campbell M Shimada**
Transport Physics	J Connor P. Strand X Litaudon R. Jaspers	T Fujita T Fukuda A Fukuyama Y Sakamoto K Toi	Y Esipchuk N Kirneva S Lebedev K Razumova V Vershkov	E Doyle* P Gohil J Kinsey J Rice E Synakowski D Mikkelsenʼ	Jiaqi Dong Aike Wang Shaoji Wang Deng Zhou Younian Wang	J. Y. Kim J. M. Kwon C. M. Ryu	R Singh V Kumar A Kumar	V Mukhovatov**
Confinement Database and Modelling	D. McDonald F Imbeaux F Ryter C Hidalgoʼ	Y Ogawa H Takenaga T Takizuka M Yagi H Yamada	A Chudnovskiy Yu Dnestrovskii V Leonov	W Houlberg* J Deboo S Kaye R Budny J Snipes	Zhengyin Cui Jinhua Zhang Changxuan Yu Yaojiang Shi Ze Gao	J.M. Park S.H. Seo C.B. Kim	I Bandyopadhyaya P Chattopadhyaya R Srinivasan R Singh	A Polevoi**
Edge Pedestal Physics	L Horton H Wilson G Saibene	K Ida Y Kamada* Y Nakashima N Oyama H Urano N. Ohyabuʼ	M Osipenko R Shurygin	T Leonard ** P Guzdar A Hubbard T Rognlien M Wade	Xiang Gao Longweng Yan Bili Lin Guosheng Xu	S.W. Yoon W.H. Ko G.Y. Park	R Singh PK Kaw J Govindrajan	M Sugihara
Scrape-off-layer and Divertor Physics	A Loarte Ph Ghendrih A Kallenbach W.Fundamenski V Philipps K McCormickʼ	N Asakura* T Kato T Nakano S Takamura T Tanabe	V Kurnaev G Kirnev	S Krasheninnikov B Lipschultz** D Whyte M Fenstermacher P Stangeby	Yu Yang Yudong Pan Shizeng Zhu Jianshen Hu	S.H. Hong K.S. Chung S.S. Kim D.C. Seo J.I. Chung	S Deshpande N Bisai R Singh	A Kukushkin C Lowry
MHD	T Hender* J Lister A Fasoli S Günter P. Martin	S Iio N Nakajima Y Ono T Ozeki M Takechi	N Ivanov S Konovalov V Lukash S Mirnov V Pustovitov	T Strait W Heidbrink R Granetz J Menard G Navratil E Lazarusʼ	Yi Liu Qindi Gao Liqun Hu Xiwei Hu Yuan Pan Xiaogang Wang	O.J. Kwon K.I. You J.G. Bak S.G. Lee	A Sen D Raju R Ganesh A Das	Y Gribov** M Sugihara
Steady State Operation	A Bécoulet A C C Sips* A Tuccillo	S Ide** A Fukuyama K Hanada T. Suzuki Y Takase Y Nakamuraʼ	V Kulygin V Vdovin A.Zvonkov	T Luce P Bonoli R Prater C Kessel M Murakami	Xianzhu Gong Xuantong Ding Xiaodong Zhang Xianming Song Jiarong Luo	Y.S. Na B.H. Park Y.S. Bae J.G. Kwak S.W. Cho	Y C Saxena D Chenna Reddy S Deshpande P K Kaw	T Oikawa
Diagnostics	A Donné* F Orsitto H. Weisen F Serra H-J Hartfussʼ	K Kawahata Y Kawano Y Kusama A Mase M Sasao	G Razdobarin A Krasilnikov V Strelkov K Vukolov V Zaveriaev	D Johnson R Boivin G Wurden G McKee T Peebles	Junyu Zhao Qinwei Yang Yan Zhou Baonian Wan Yinxian Jie	H.G. Lee H.K. Na J.H. Lee Y.W. Nam W.H. Choe	P Vasu C V S Rao R Jha P K Atrey	A Costley** T Sugie

*** Chair; ** Co-Chair ; †Coordinating Committee Contact Person ; ʼStellarator** **(15 March 2007, M. Shimada ; michiya.shimada@iter.org)**

Meetings and Workshops

- The Topical Groups hold about two meetings annually to review the world wide progress in their topical area, to discuss open scientific issues, and to recommend research topics that should be carried out and their priorities. One of these meetings is usually around a major international conference to minimize travel.

- The Coordinating Committee meets about once a year to review the work of Topical Physics Groups, to consolidate their recommendations, and to develop an annual list of ITPA research tasks for the world tokamak community to work on.

ITPA Meetings Completed and Planned in 2007

Topical Group	Location	Date	Comment
Diagnostics	Princeton, USA	26-30 Mar.	
Transport Physics	Lausanne, Switzerland	7-10 May	
Confinement DB & Modelling			
Pedestal and Edge	Garching, Germany	7-10 May	
Sol and Divertor Physics			
Steady State Operation	NFRC, Daejeon, Korea	9-11 May	Before the IAEA-TM on Steady State Operation
MHD	General Atomics	21-24 May	
Coordinating Committee	Cadarache	18-20 noon June	
Transport Physics	Naka	1-3 Oct.	After H-mode WS(26-28 Sept., Tsukuba)
Confinement DB & Modelling			
Pedestal and Edge			
MHD	IPP-Garching	11-12 Oct.	After IAEA TM on Energetic Particles(8-10 Oct.)
SSO	IPP-Garching	October 2007	
Diagnostics	Chengdu, China	29 Oct. – 2 Nov.	
SOLDIV	Toledo, Spain	January 7-10, 2008	In conjunction with PSI paper selection meeting
IEA/ITPA Joint X Planning	JET-UK	November 29-30, 2007	

ITPA Coordinates High Priority Research Tasks to Support ITER

Definition of High Priority Research Tasks: a small number of R&D tasks which provide a focus for the Topical Group's activities in a timeframe of 1-2 years and which should be determined on the basis of their likely importance, both in increasing understanding of fusion plasmas and in providing increased confidence in achieving significant fusion gain in proposed long-pulse burning plasma facilities, as well as on the probability of achieving significant progress within this timeframe.

ITPA High Priority Research Tasks 2006–2007

Diagnostics	▪ Assessment of the various options for the Vertical Neutron Camera to measure the 2D n/ α source profile and asymmetries in this quantity, and assessment of the calibration strategy and calibration source strength needed. ▪ Development of methods of measuring the energy and density distribution of confined and escaping α's ▪ Review of the outstanding radiation effects work for ITER ▪ Determination of life-time of plasma facing mirrors used in optical systems. ▪ Development of measurement requirements for measurements of dust, and assessment of techniques for measurement of dust and erosion.
MHD	▪ Continue development of the new disruption DB including conventional and advanced scenarios to initially study fast Ip quenches and halo currents. ▪ Develop disruption mitigation techniques particularly at high performance and by noble gas injection and understand influence of MHD on impurity penetration. Validate 2 and 3-D codes, in particular MHD and radiation models, on gas injection. Develop reliable disruption prediction methods. ▪ For NTMs complete 2/1 ρ^* scaling studies, validate ECCD control models against data (including modulation), develop sawtooth seed island control to high beta and high fast particle regimes, initiate development of a 3D MHD model (including seeding) and specify diagnostics for NTM detection. ▪ For RWMs understand mode damping through cross-machine experiments. Study $n \neq 1$ RWMs. Continue benchmark tests of theory models for RWM feedback and experimentally study feedback control at low rotation. Study coil systems for RWM control in ITER and specify diagnostics. ▪ Understand intermediate-n AEs ; redistribution of fast particles from AEs; and perform theory-data comparisons on damping and stability. ▪ Specify for ITER the low frequency noise in the diagnostic signals used in feedback loops (for both RWM and vertical control).

ITPA High Priority Research Tasks 2006–2007

Pedestal and Edge

- Improve Predictive Capability of Pedestal Structure through Profile Modeling and Experimental Studies
- Dimensionless cross machine comparisons to isolate physical processes; asses dependence on roh* , ripple, rotation, and shape.
- Measurement and modeling of inter-ELM transport
- Establish profile database for modeling joint experiments including effects of neutrals
- Physics based empirical scaling
  - Collaboration with CDBM to improve scalar database characteristics and utilization
- Improve Predictive Capability of ELM characteristics through experimental studies and theory / modeling analysis, and develop small ELM and quiescent H-mode regimes and ELM control techniques
  - Define physics requirements for pellet injection as ELM control schemes in ITER
  - Define physics requirements for ergodic field application as ELM control schemes in ITER
  - Integrate observations of ELM crash dynamics and initiate comparisons with developing models
- Categorize small ELM regimes based on cross machine comparisons

Divertor and SOL

- Understanding of Tritium retention, and development of efficient T removal methods.
  - Compare tile-side D retention level (difficult to remove) across tokamaks
  - Characterize macroscopic (overall) D-retention in tokamaks and laboratory experiments
  - Comparison of various D/T removal techniques for carbon PFC tokamaks
- Understand the effect of ELMs/disruptions on divertor and first wall structures
  - Update specification of power levels and areas of deposition during ELMs and disruptions
  - Development of more precise 2-3D measurements of where power goes in disruptions/ELMs
- Improve measurements & understanding of plasma transport to targets and walls, for better predict heat load, and effects on the core plasma
  - Exploring the role of non-diffusive radial transport (i.e. blob/ turbulence) on wall heat/particle
  - loadings, macroscopic transport(χ and D), and driving SOL flows (parallel transport).
  - Neutral density benchmarking of physic models in current experiments and ITER.
  - Code-code comparisons with no drifts(at this stage), and drift
- Understand how conditioning and operational techniques can be scaled to reactor devises
  - Implications of a metal wall for startup, fuel retention, density control and core impurity levels
- Compare startup/ramp-down experiences, and evaluate influence of limiter configuration on SOL

ITPA High Priority Research Tasks 2006–2007

Steady State Operation	▪ Continue the focussed modelling activity on ITER Hybrid and Steady state scenarios, using standard (and common) sets of input data. ▪ Assess requirements for real-time control in ITER and increase collaboration in joint experiments on real time control. ▪ Pedestal studies: Experiments to document pedestal in advanced scenarios, modelling of pedestal, pedestal conditions in ITER (maximum T_{ped}). ▪ Code benchmarking of LHCD and NBCD and implications for ITER. ▪ The current rise of advanced scenarios, in particular requirements for the ITER start up phase. This subject should be studied in collaboration with the DSOL TG; the scenario for start up and use of outboard limiters should be optimised together.
Transport Physics	▪ Utilize upgraded machine capabilities to obtain and test understanding of improved core transport regimes with reactor relevant conditions, specifically electron heating, Te~Ti and low momentum input, and provide extrapolation methodology ▪ Develop and demonstrate turbulence stabilization mechanisms compatible with reactor conditions, e.g. s-α-stabilization, shear flow generation, q-profile. Compare these mechanisms to theory ▪ Study and characterize rotation sources, transport mechanisms and effects on confinement and barrier formation ▪ Quantitative tests of fundamental features of turbulent transport theory via comparisons to measurements of turbulence characteristics, code-to-code comparisons and comparisons to transport scalings
Confinement Database and Modelling	▪ Resolve the differences in β scaling in H-mode confinement ▪ Develop a reference set of ITER scenarios for standard Hmode, steady-state, and hybrid operation and submit cases from various transport code simulations to the Profile DB ▪ Resolve which is the most significant confinement parameter, ν^* or n/n_G ▪ Understand the aspect ratio dependence of the L-H power threshold ▪ Understand the collisionality dependence of density peaking ▪ Develop common technologies for integrated modeling, e.g. frameworks, code interfaces, data structures

ITPA Manages the Planning and Execution of Joint Experiments Among the ITPA Parties' Tokamak Programs

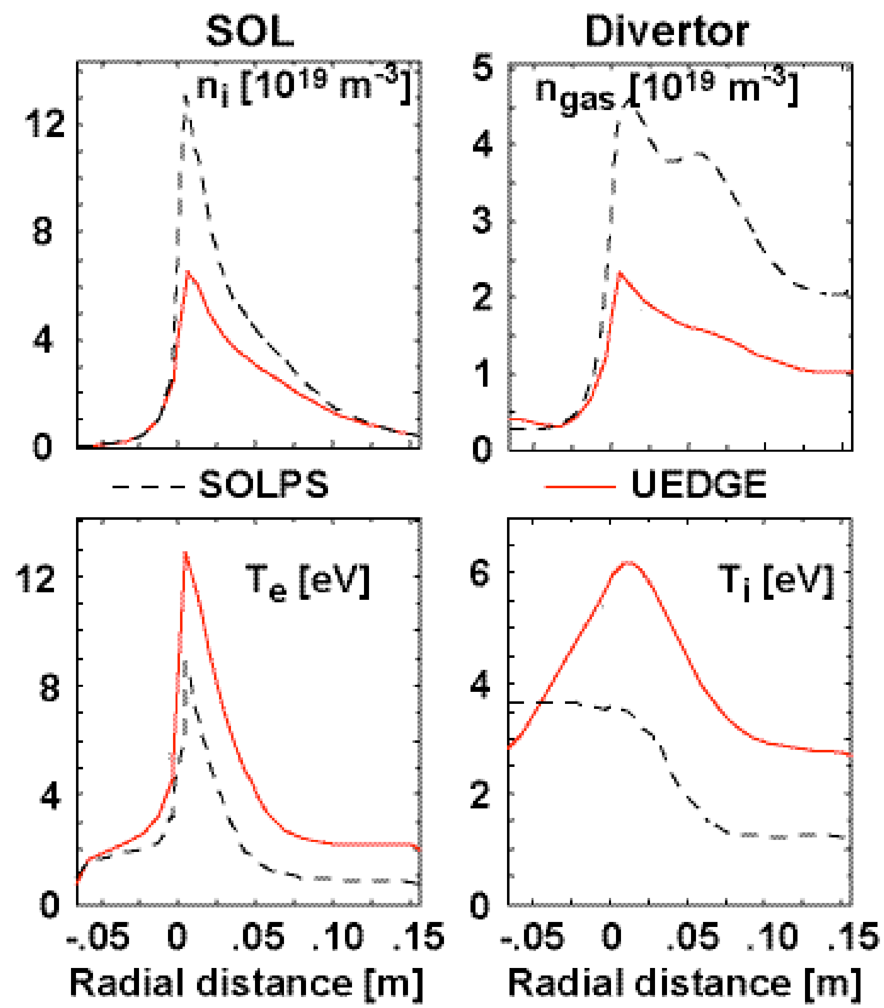
Joint Experiments 2006-07	
Closed or Completed 2005	19
Closed or Completed 2006	4
Dropped	4
Defered to 2007	10
Prepare for 2007	6
New Results Obtained	34
New Proposals	11
Total	**88**
Total Active	**61**

ITPA-IEA_JointX_Master_List_07_v5.xls
Spokesperson in Green
For machines, red = committed, green = considering, blue = not participating, black = already finished

Topical Group	Proposal Title	Keypersons [1]	Devices [2]	Ctg	Comments/ Recommendations/ Results
MHD, Disruptions & Control	Comparison of sawtooth control methods for neoclassical tearing mode suppression	O. Sauter, R Pinsker, R La Haye (DIII-D), H. Zohm (AUG), S. Coda(JET), R Buttery (JET), ,J Menard (NSTX), T Goodman (TCV), Yi Liu (HL2A), S	AUG , DIII-D, JET, NSTX, TCV, HL2A, Cmod, FTU, JT-60U	E	Report, new results
MHD, Disruptions & Control	Low beta error field experiments	S Wolfe, I Hutchinson (C-Mod), T Hender(JET), M. Schaffer (DIII-D), T. Scoville (DIII-D), R Koslowski (TEXTOR), D Howell (MAST), Menard (NSTX)	C-mod, TEXTOR, MAST, DIII-D, NSTX, JET(done)	E	Report; closed 2006, work finished

Modelling cross-benchmarking effort very effective

- **Effort underway to compare the various edge modelling codes**
  - Initially just EDGED2D (JET) and SOLPS
  - UEDGE (LLNL) and SOLDOR (JAEA) now added
- **Very simple case still leads to significant differences across models**



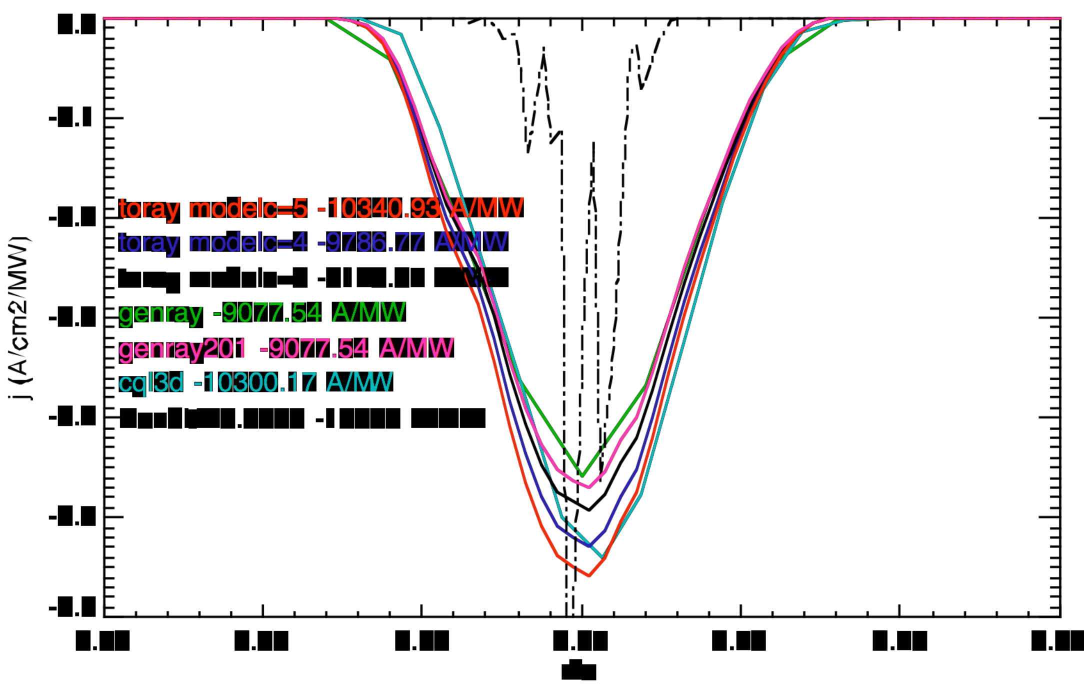
Coster, Bonnin, Rognlien

Benchmarking of ECRH Codes

ECRH:

Remarkable effort on code benchmarking: Now ready for publication.

→ use in assessing NTM stabilisation using ECCD, gives confidence for "standard" off-axis current drive for steady state scenarios, and provides a sound modelling basis for the choice of the ITER launcher systems.



ECCD, off axis

Comparisons of ICRH Codes

ICRH code comparisons: ITER SCENARIO 2

- Power balance - TORIC

P(2ΩT) ~ 50 %

P(ELD) ~ 35%

P(D) ~ 1.8%

P(alpha) ~ 14 %

Numerical profiles from spreadsheet, Bi-maxwellian distribution for alphas

- Power balance – AORSA2D

P(2ΩT) ~ 45 %

P(ELD) ~ 38%

P(D) ~ -0.5%

P(alpha) ~ 17 %

Approximate analytic profiles, slowing down distribution for alphas.

- PSTELION (full wave 3D,N=27)

P(2ΩT) ~ 58 %

P(ELD) ~ 41%

P(D) ~ 1%

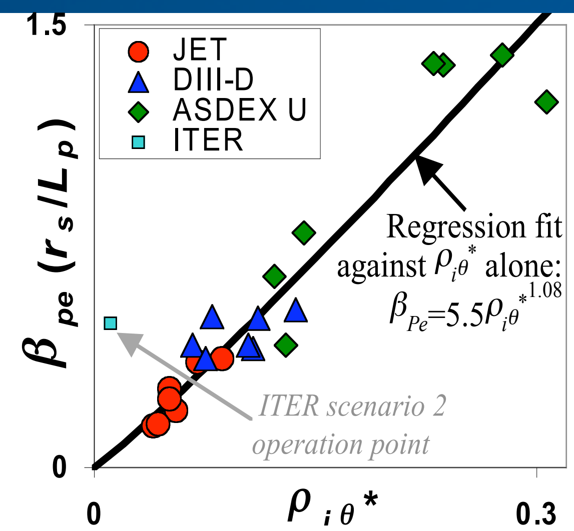
P(alpha) ~ 0.2 %

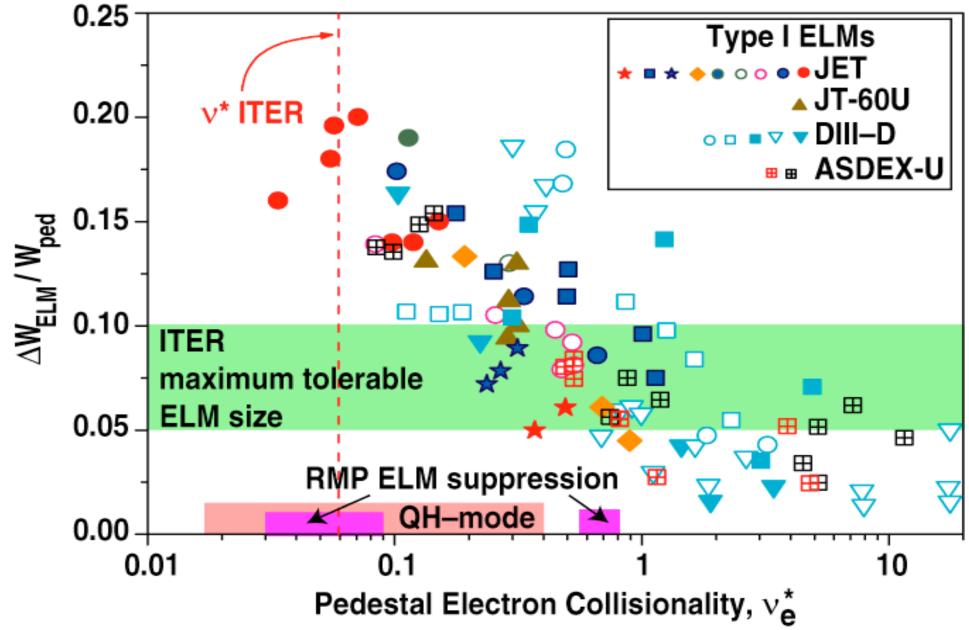
Bi-maxwellian distribution for alphas ?

Showing good progress but physics is much more complex (compared to ECRH/ECCD).

ITPA Maintains the Tokamak Databases of the ITPA Parties

Database	Responsible ITPA Topical Group
International Diagnostic DB	Diagnostics
Radiation Effects Database	Diagnostics
Disruption DB	MHD
DB on Steady State scenarios	SSO
ITB DB	Transport Physics
Transition DB	CDB&M
Energy Confinement time DB	CDB&M
Profile DB	CDB&M
Pedestal Scalar DB	Edge Pedestal
Pedestal DB	Edge Pedestal
ELM DB	SOL&Divertor



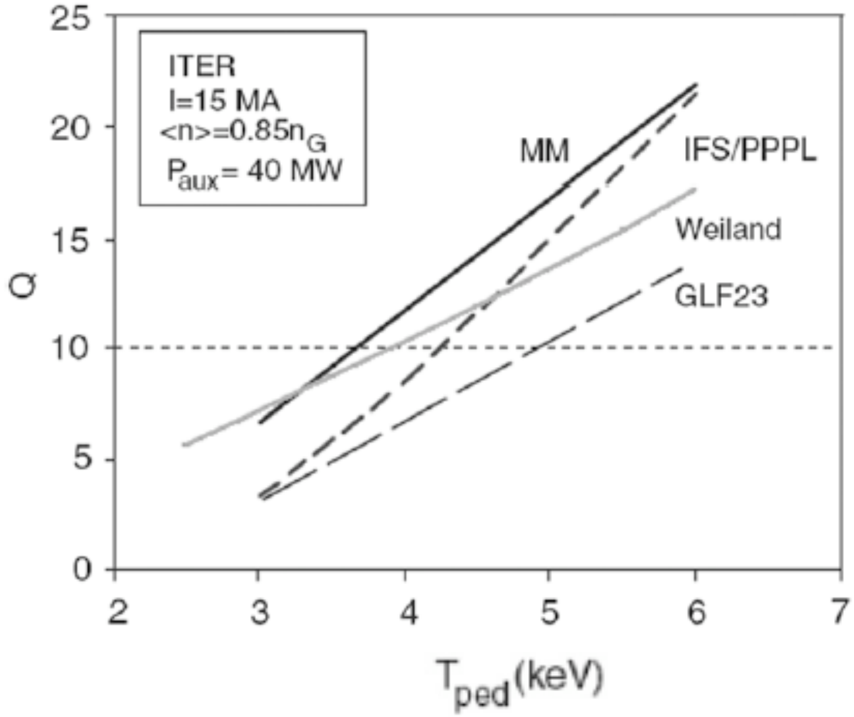


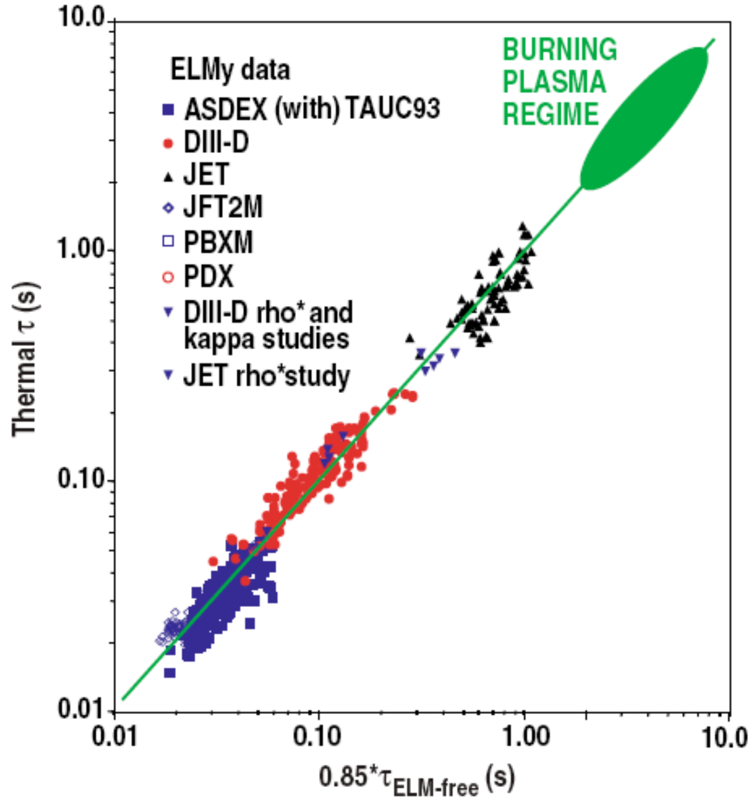
Multi-machine global confinement database and multiple theoretical models used to project confinement in ITER

- **Empirical Confinement Scaling**

$$\tau_E\text{, th, ELMy} = 0.85\ \tau_E\text{, th, ELM-free}$$
$$= 0.031\ I_p^{1.06}\ B^{0.32}$$
$$P^{-0.67}\ M^{0.41}\ R^{1.79}\ n_e^{0.17}\ \varepsilon^{-0.11}\ \kappa^{-0.6}$$

- **Dimensionless Wind Tunnel Scaling provides a more fundamental basis.**

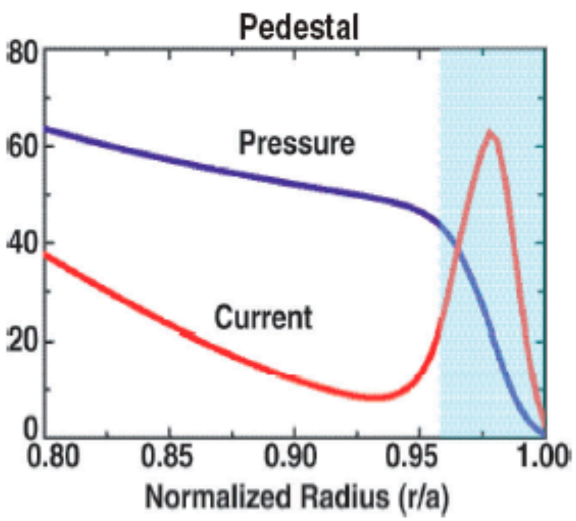


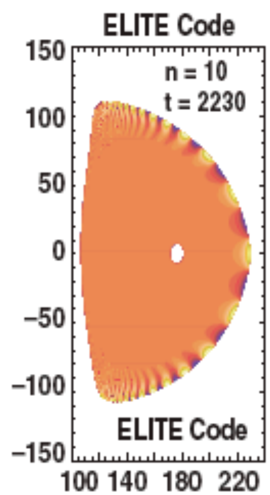


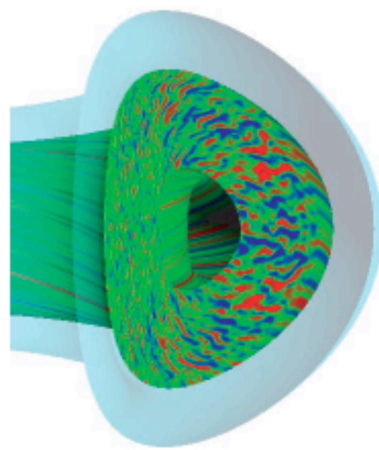
- **Theory Models also used to project confinement.**

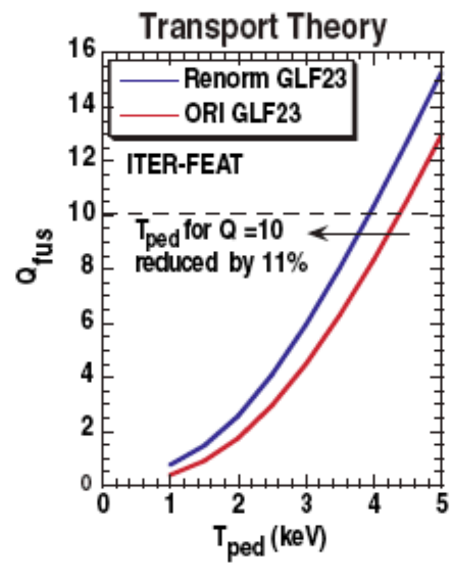
Pedestal Physics and Turbulence Codes Project ITER Performance

BASIC PEDESTAL PHYSICS + GLF23 TRANSPORT CODE (CALIBRATED TO GYRO CODE) = PERFORMANCE PROJECTIONS FOR ITER

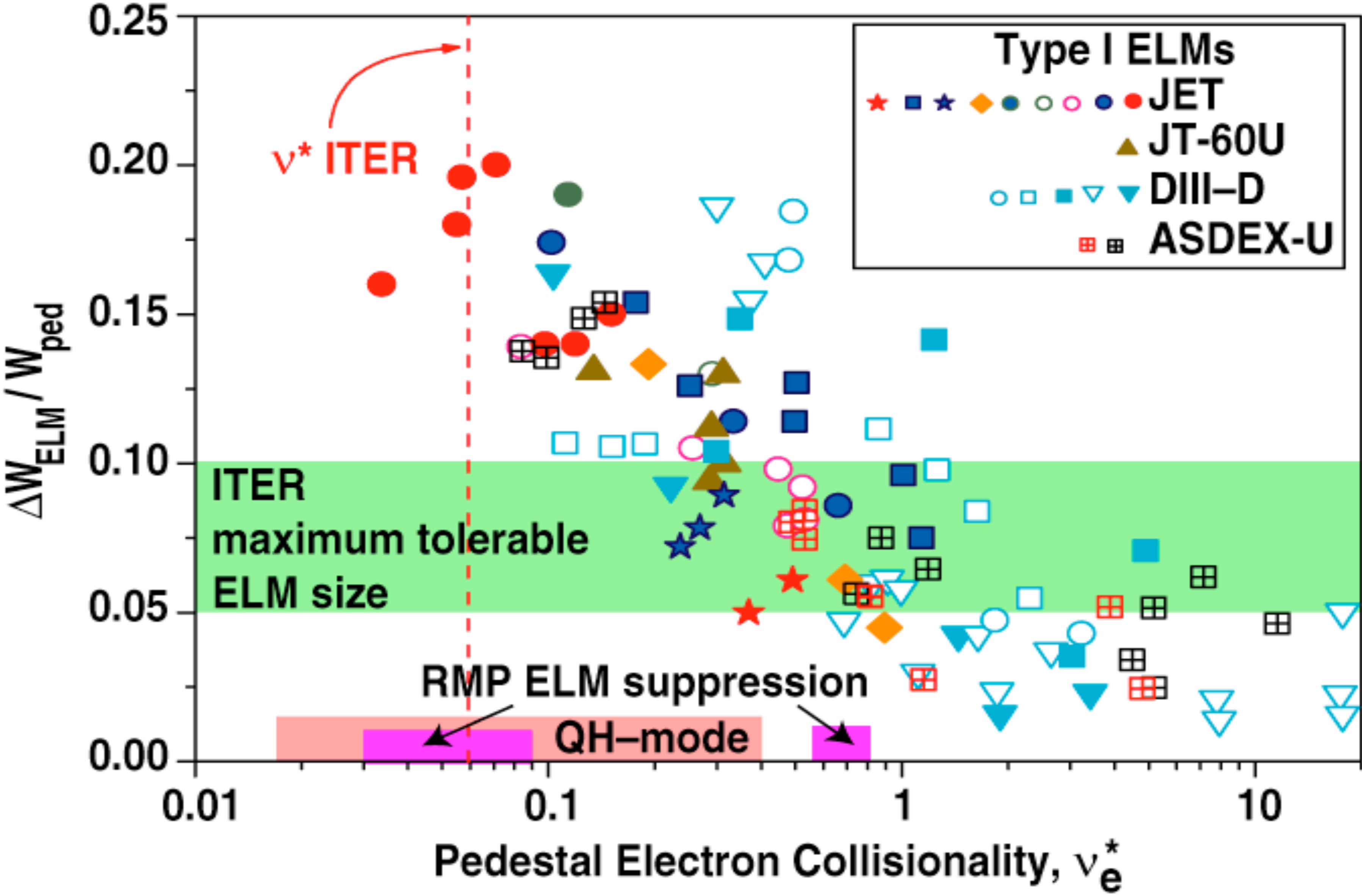




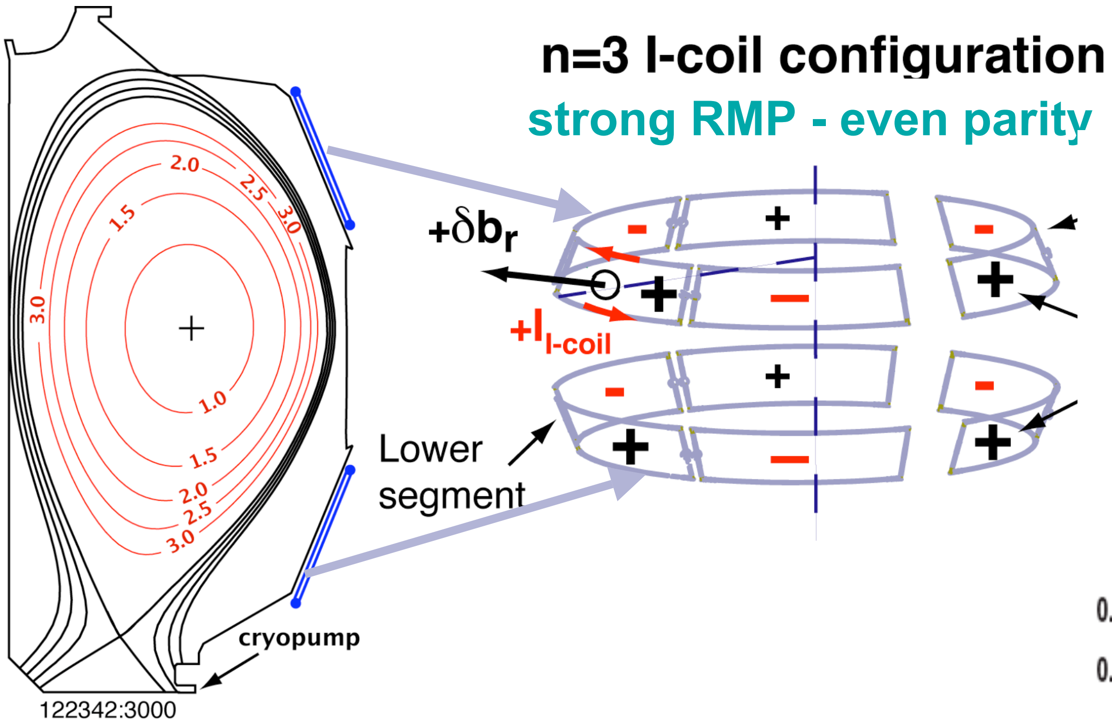




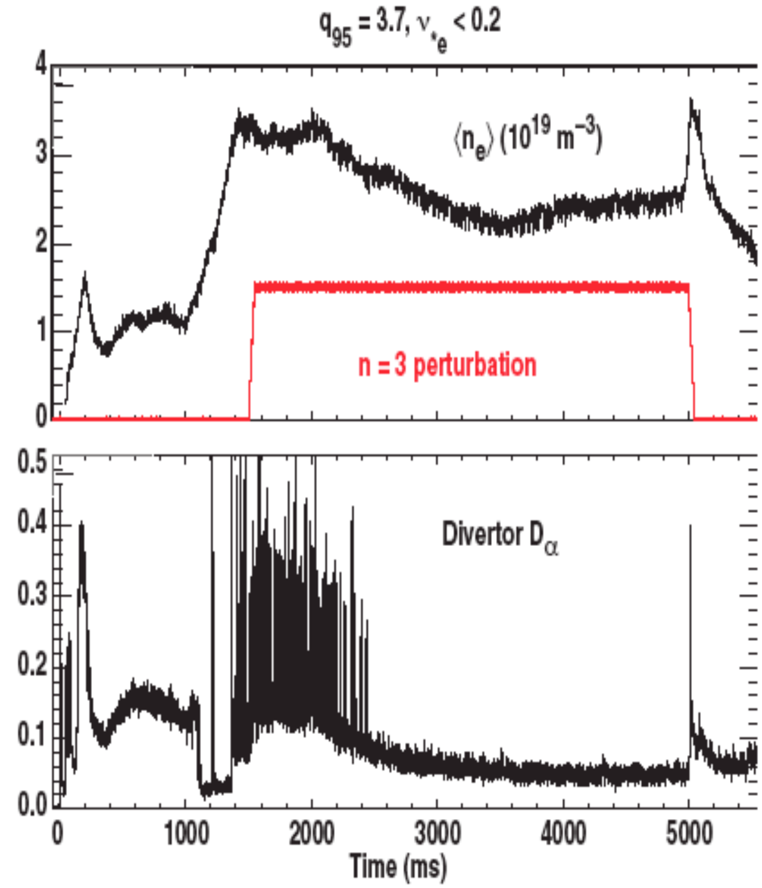
International Database Shows ELMS Will Be too Large in ITER at the ITER Collisionality



Edge Localized Resonant Magnetic Perturbations Eliminate ELMs at ITER's Pedestal Collisionality



- **Flexible control of poloidal (m) spectrum with n=3, even and odd parity, toroidal phasing**
- **Pumping used to reduce ν^*_e initially in weakly shaped (low δ) plasmas and recently in high δ ITER similar shapes**

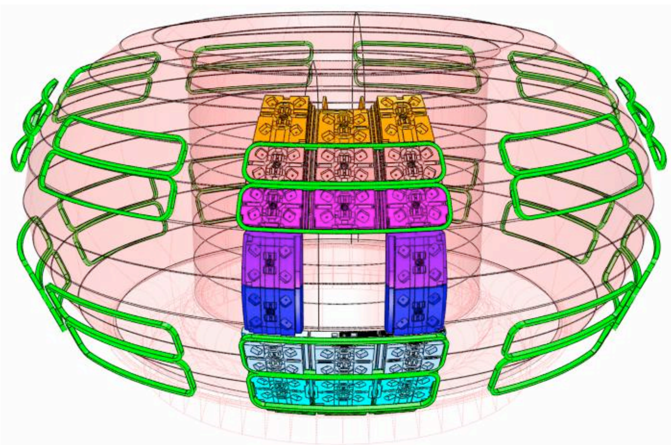


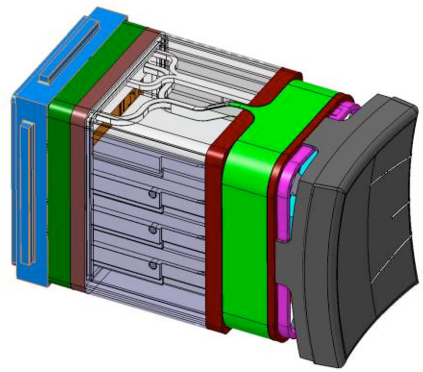
Previous ELM Coil Configurations

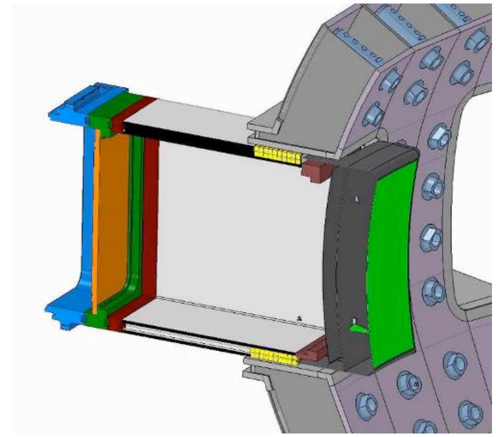
Various locations investigated

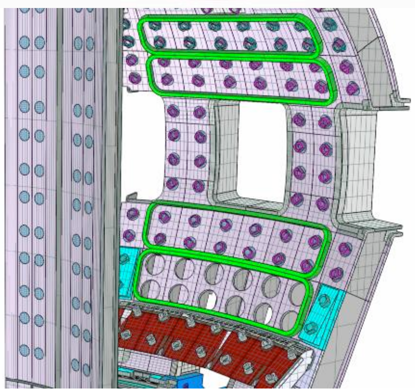
(Cryostat, VV coolant passage, Port plugs, vacuum)

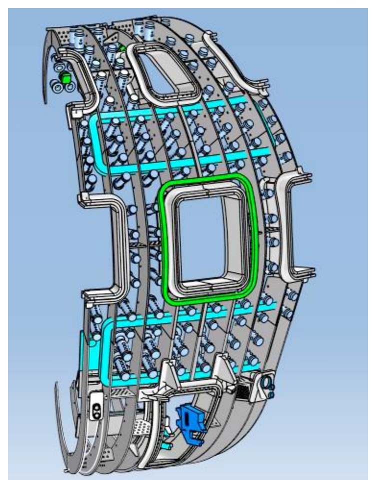
Focus here on the previous in-vacuum options

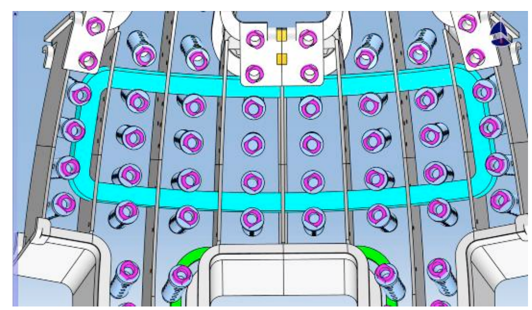




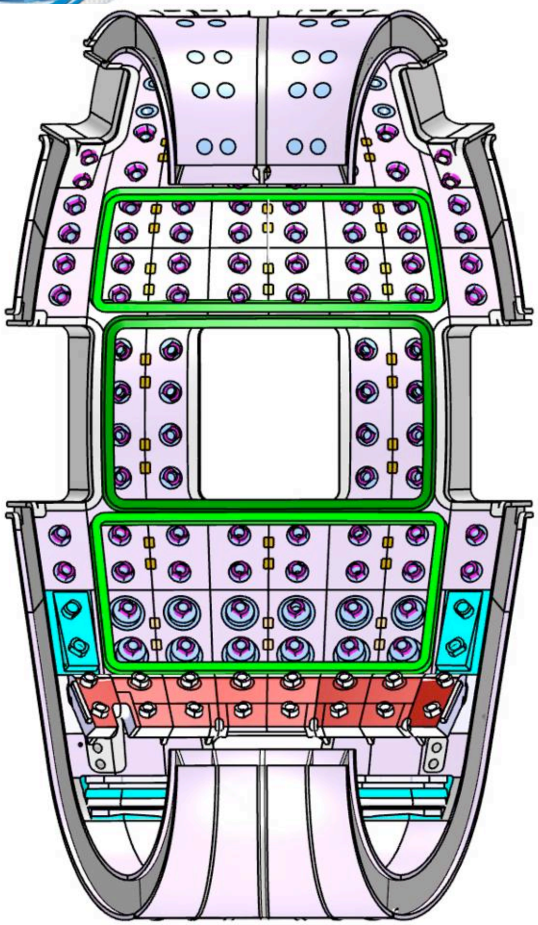


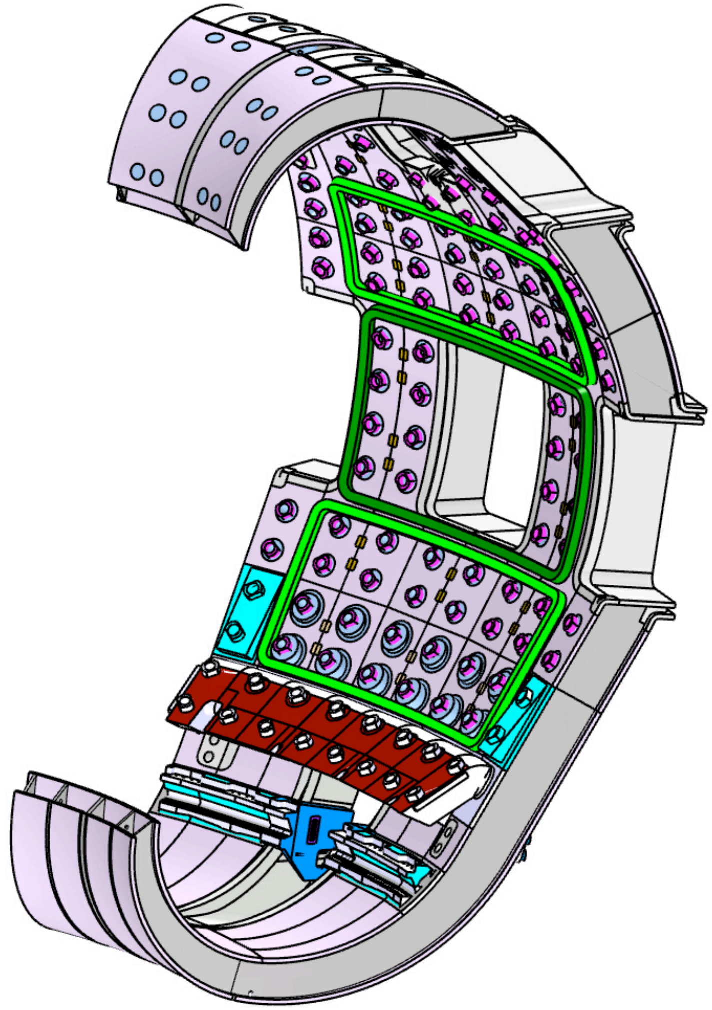






ELM VV02 Configuration

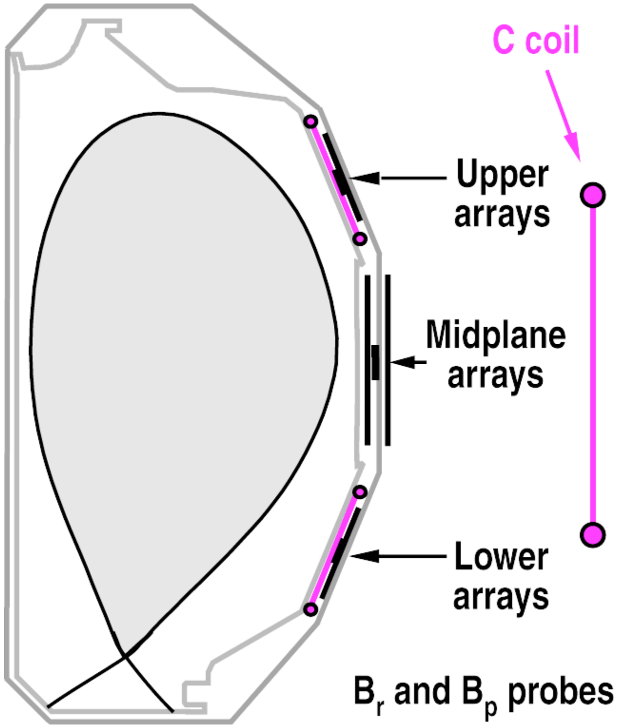




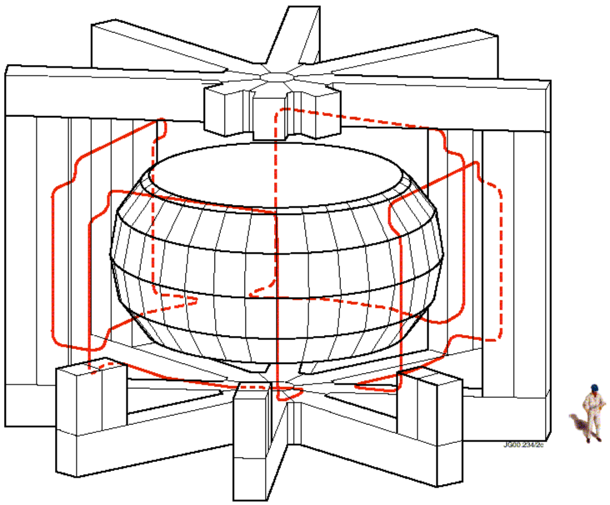
- (3) coils per sector (27 total)
- Approximate cross section 120mm x 120mm
- Coils contained in an actively cooled shell, bolted onto VV welded rail

MHD High Priority areas - RWMs

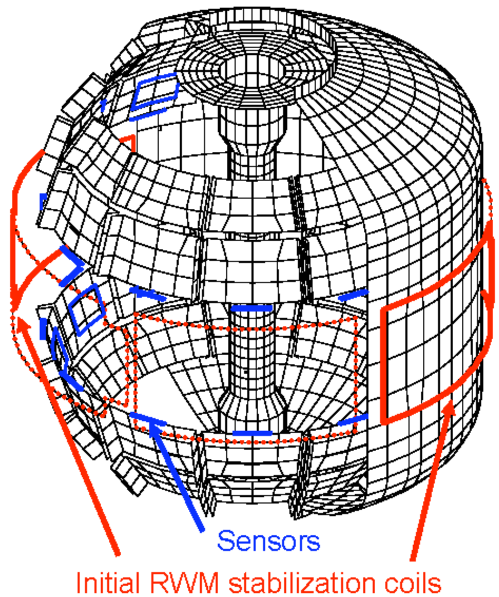
- Moving to multi-machine studies in this area
- Several machines have non-axisymmetric coils for RWM MHD spectroscopy



DIII-D

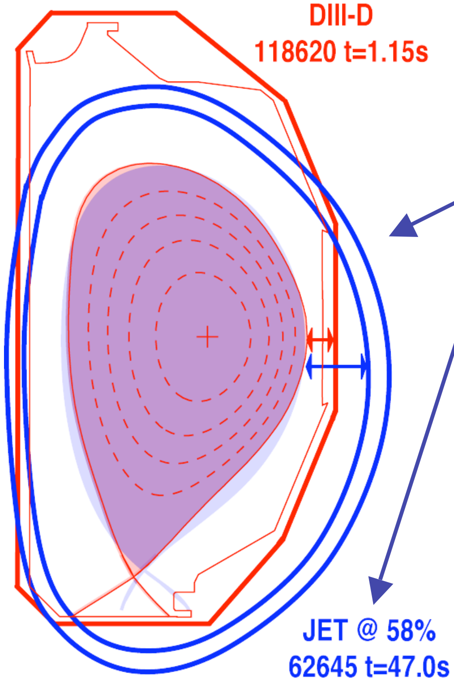


JET

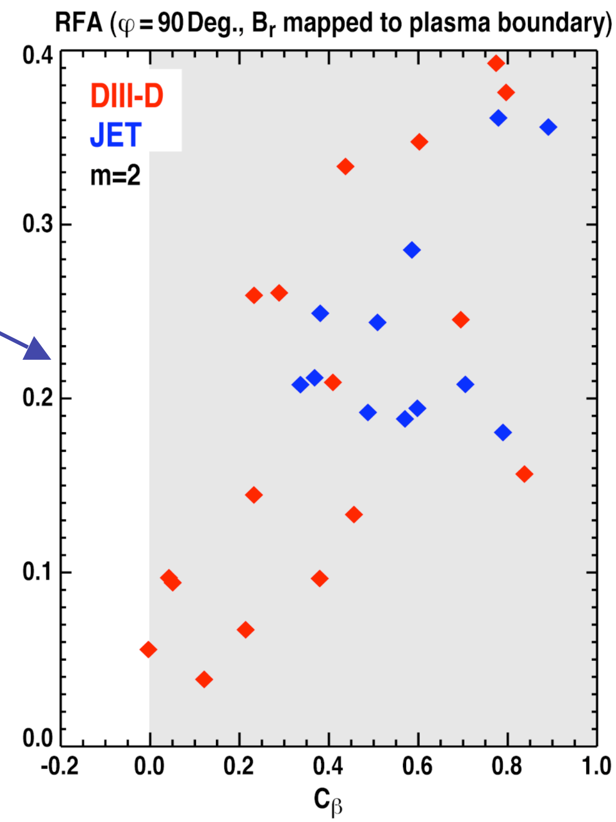


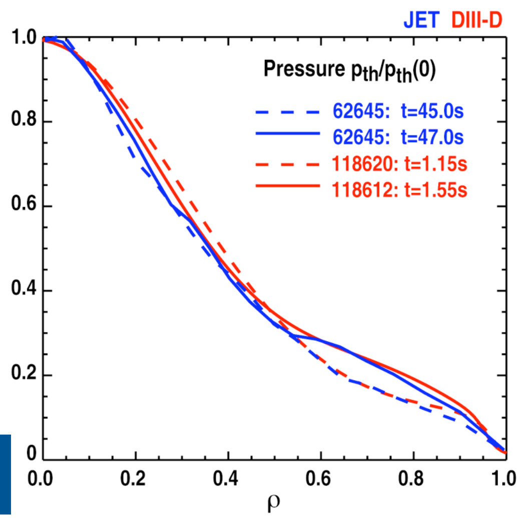
NSTX

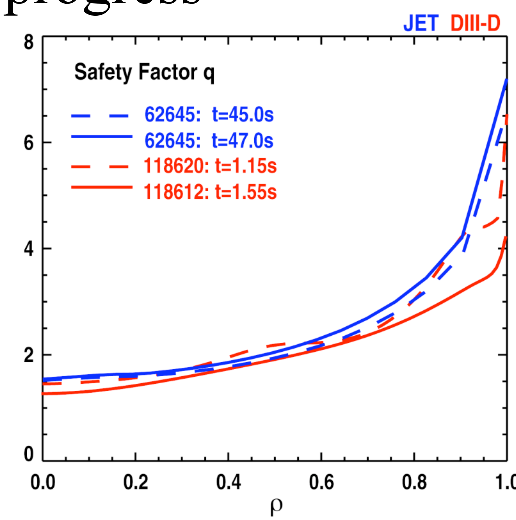
MHD High Priority areas - RWMs



- DIII-D/JET similarity expt
- Plasma equilibrium, profiles well matched
- RFA agrees when geometry effects accounted for
- Further more accurate VALEN correction in progress

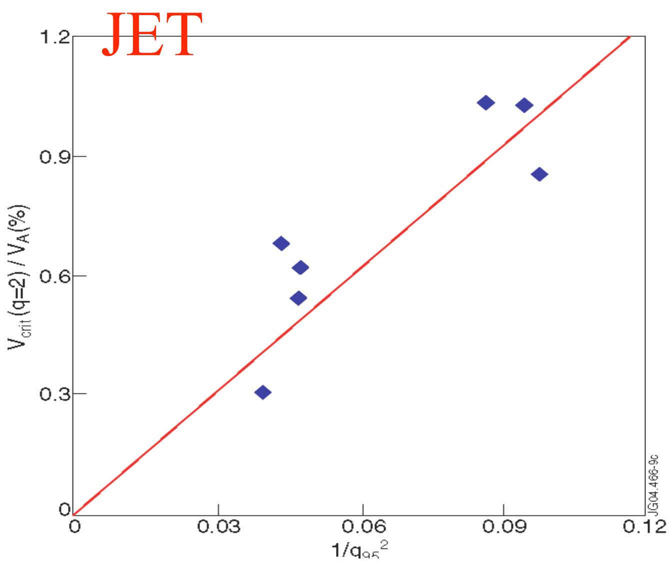


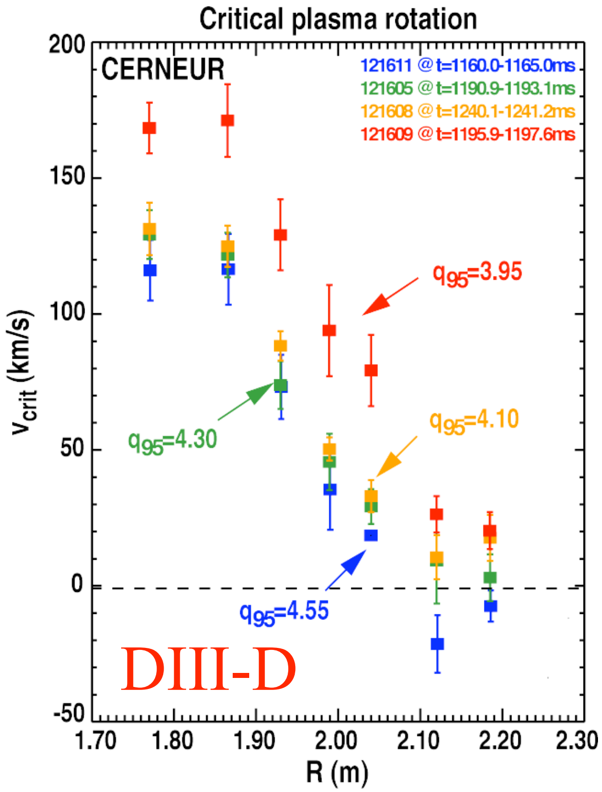


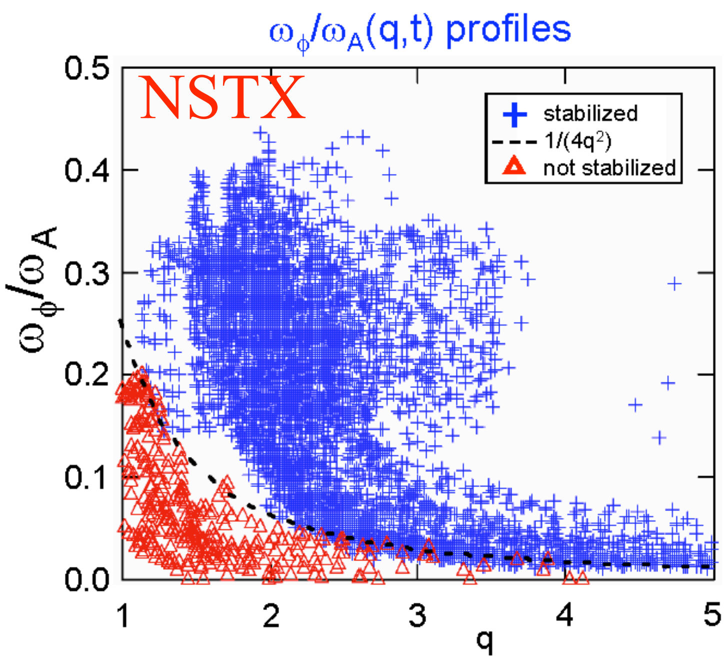


MHD High Priority areas - RWMs

- Critical rotation for RWM scales as $1/q^2$

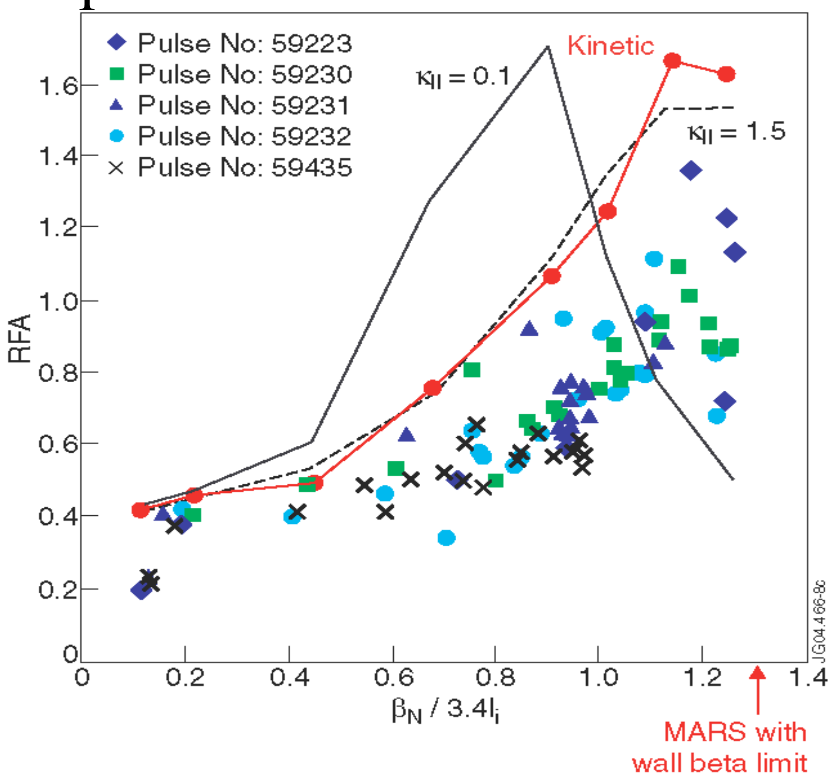


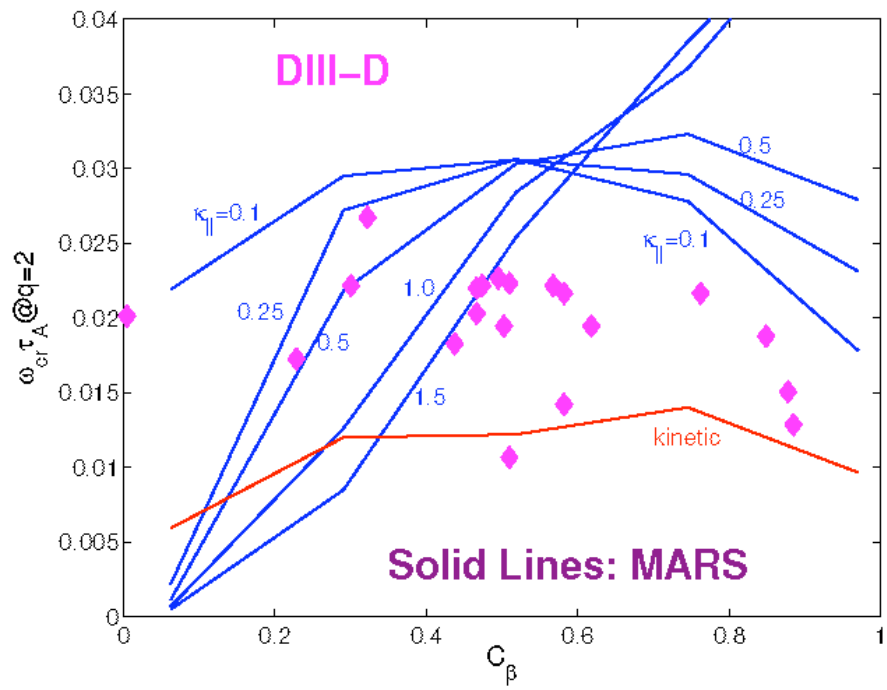




MHD High Priority areas - RWMs

- Way forward is to use data to benchmark theory models → ITER predictions



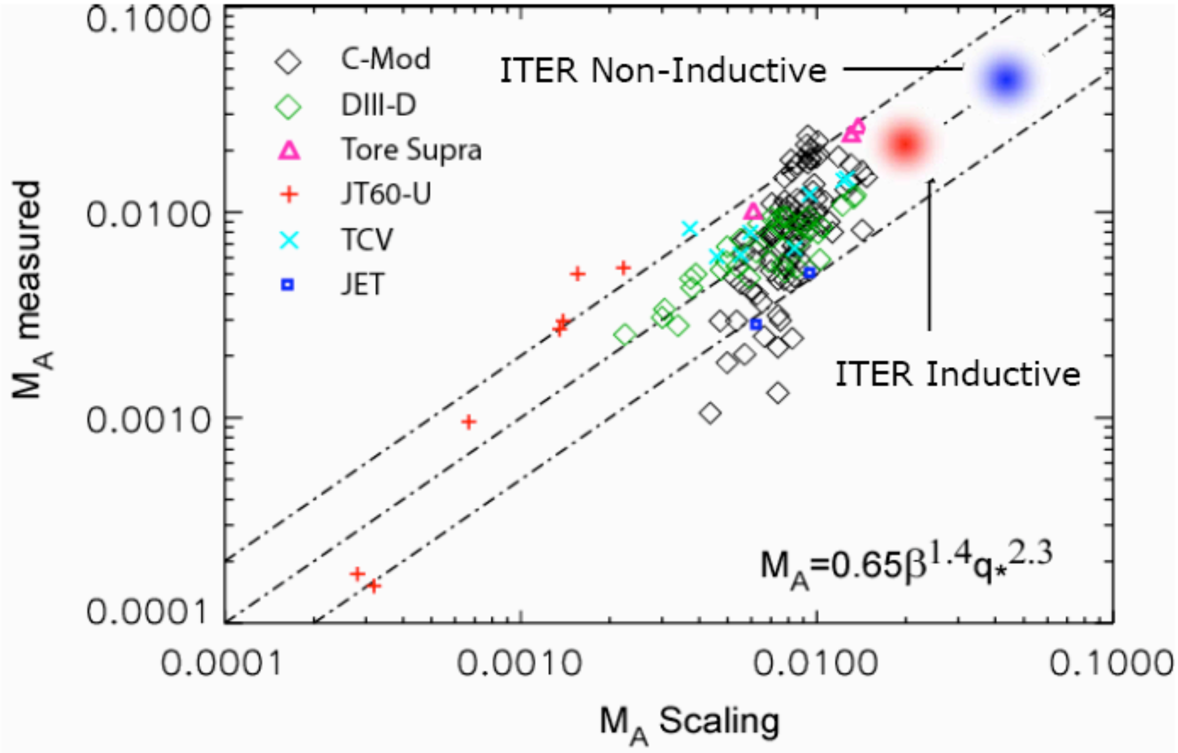


Hender and Liu IAEA 2004

- Semi-kinetic model ~benchmarked on DIII-D and JET data ⇒ for ITER intrinsic rotation very marginal for RWM stability

Inter-machine scaling of spontaneous plasma rotation

- **On ITER, spontaneous (intrinsic) rotation may be comparable to NBI induced rotation rates. First international, multi-machine database for intrinsic rotation (J. Rice 2006 IAEA). Rotation scaling in terms of Mach number M_A) developed from the international database**



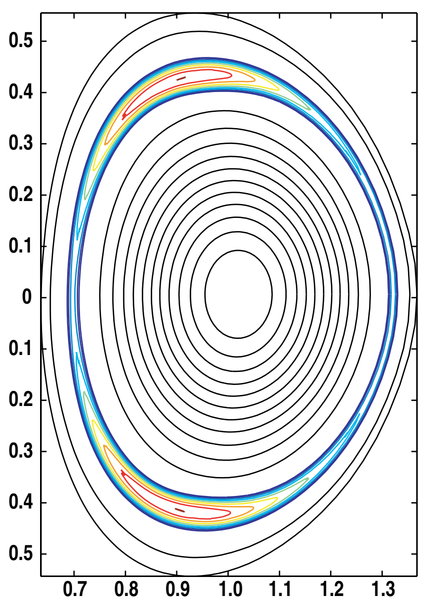
TEARING MODES

Classical

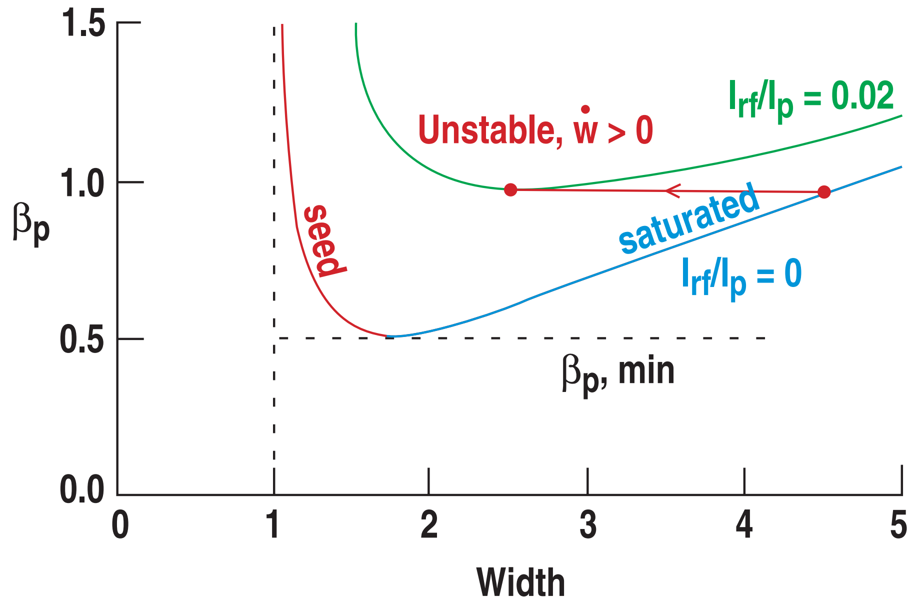
- Finite resistivity
- Current can diffuse and form clumps — magnetic islands — on rational q flux surfaces
- Driven by ∇J
- Growth time 10s of milliseconds

Neoclassical

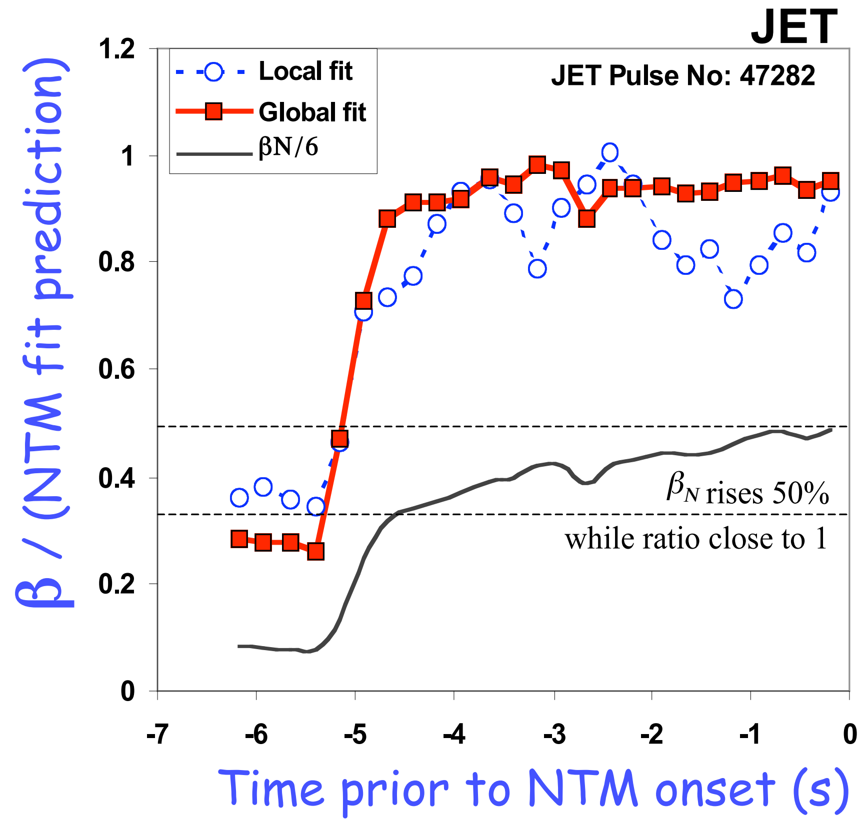
- ∇P=0 in island removes equilibrium bootstrap current
  – Helical current perturbation amplifies seed island
- Providing auxiliary current drive predicted to stabilize NTM



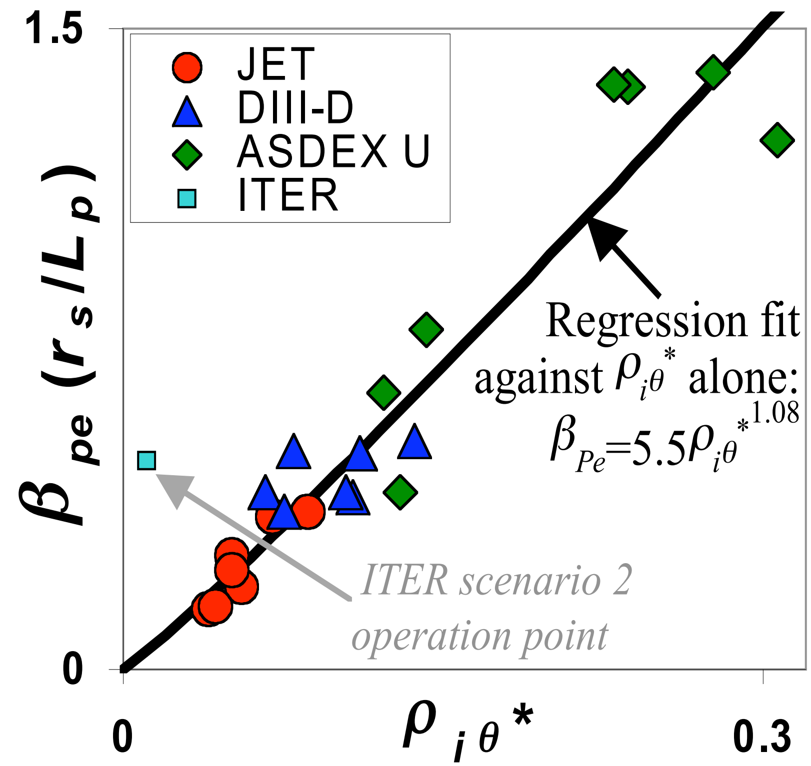
PEST–III



MHD High Priority areas - NTMs physics



Onset β



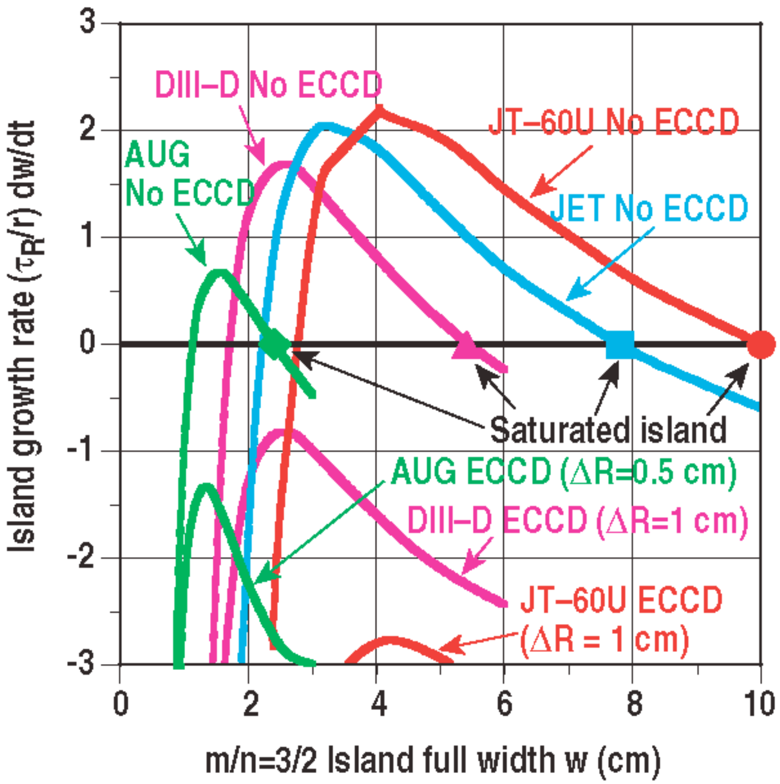
Critical β

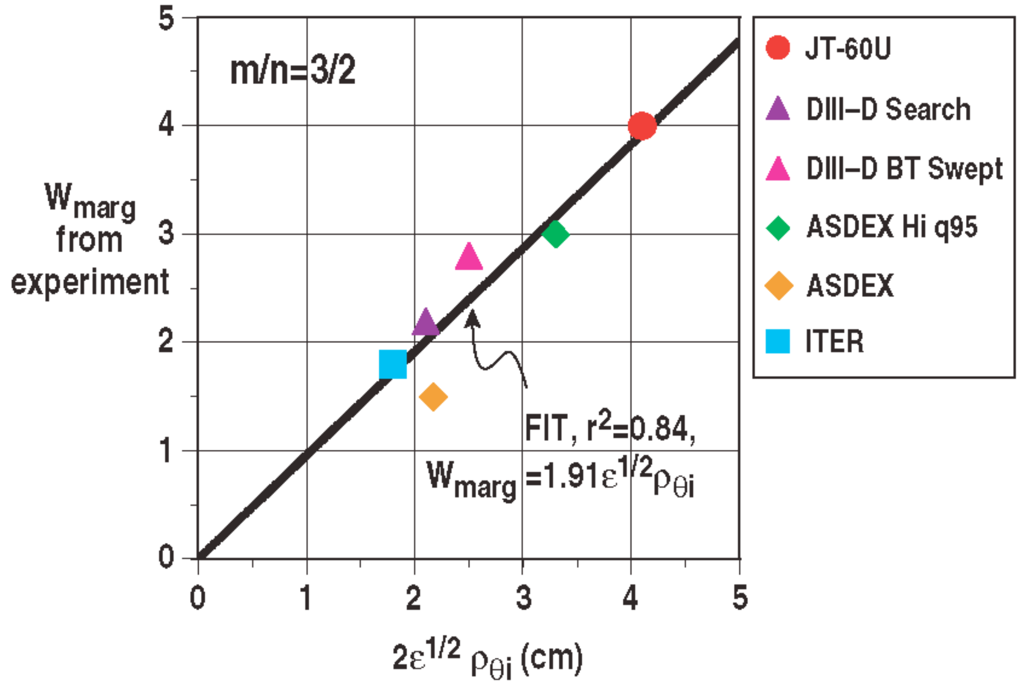
- Understanding that seeding plays a key role in NTM triggering
- Extensive cross machine studies (MDC-3) show $\beta_{crit} \sim \rho_i$

MHD High Priority areas - NTMs ECCD Feedback

- Extensive benchmarking in progress to validate ECCD NTM stabilisation requirements for ITER

$$\frac{\tau_R}{r_s}\frac{dW}{dt} = r_s\Delta' + a_2 \frac{j_{bs}}{j_{\|}}\frac{L_q}{W}\left[1 - \frac{W_{marg}^2}{3W^2} - K_1 \frac{j_{ec}}{j_{bs}}\right]$$

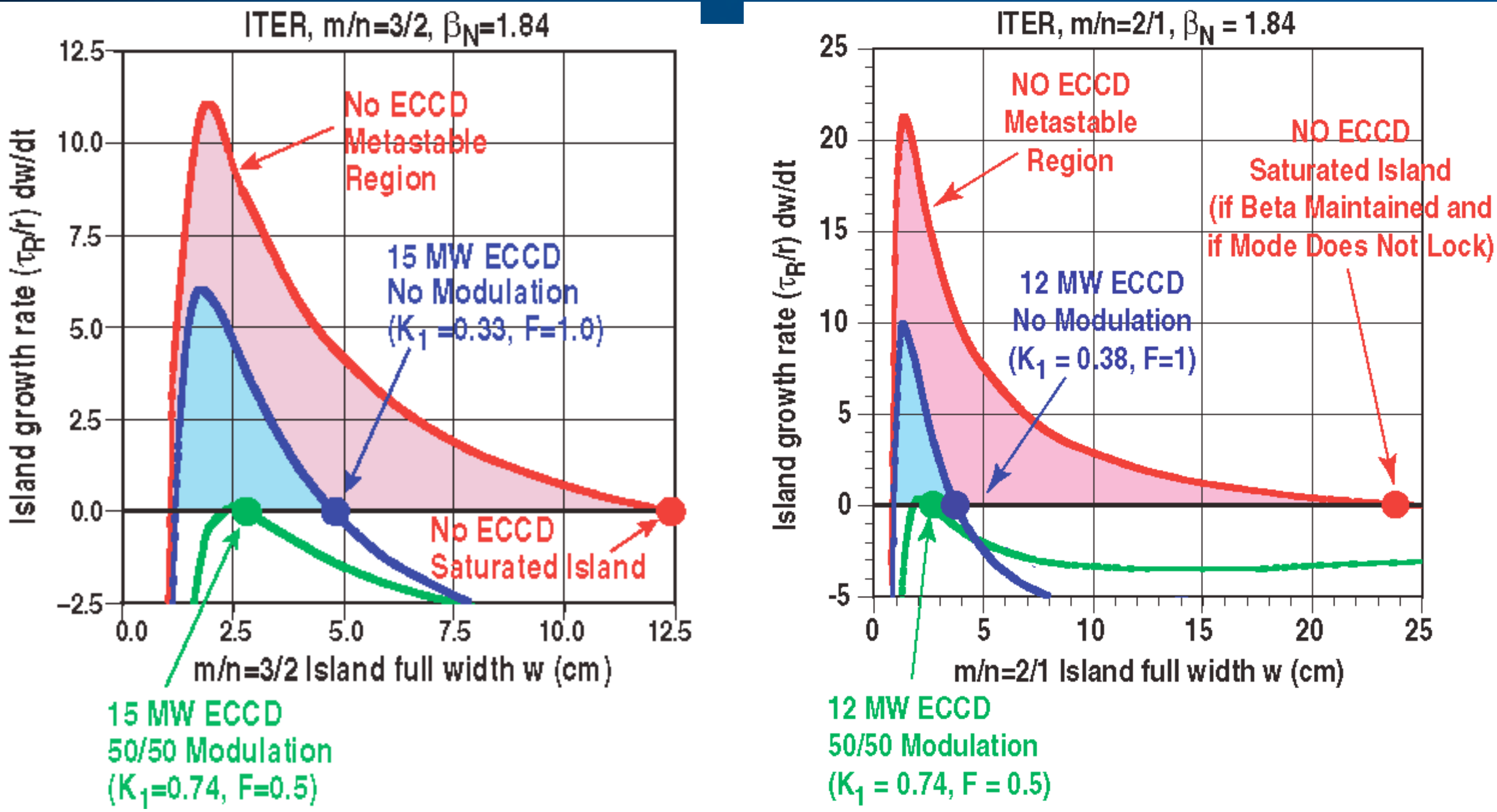




R La Haye, R Buttery, H Zohm, N Hayashi et al IAEA TCM Como 2005

043-05/rs

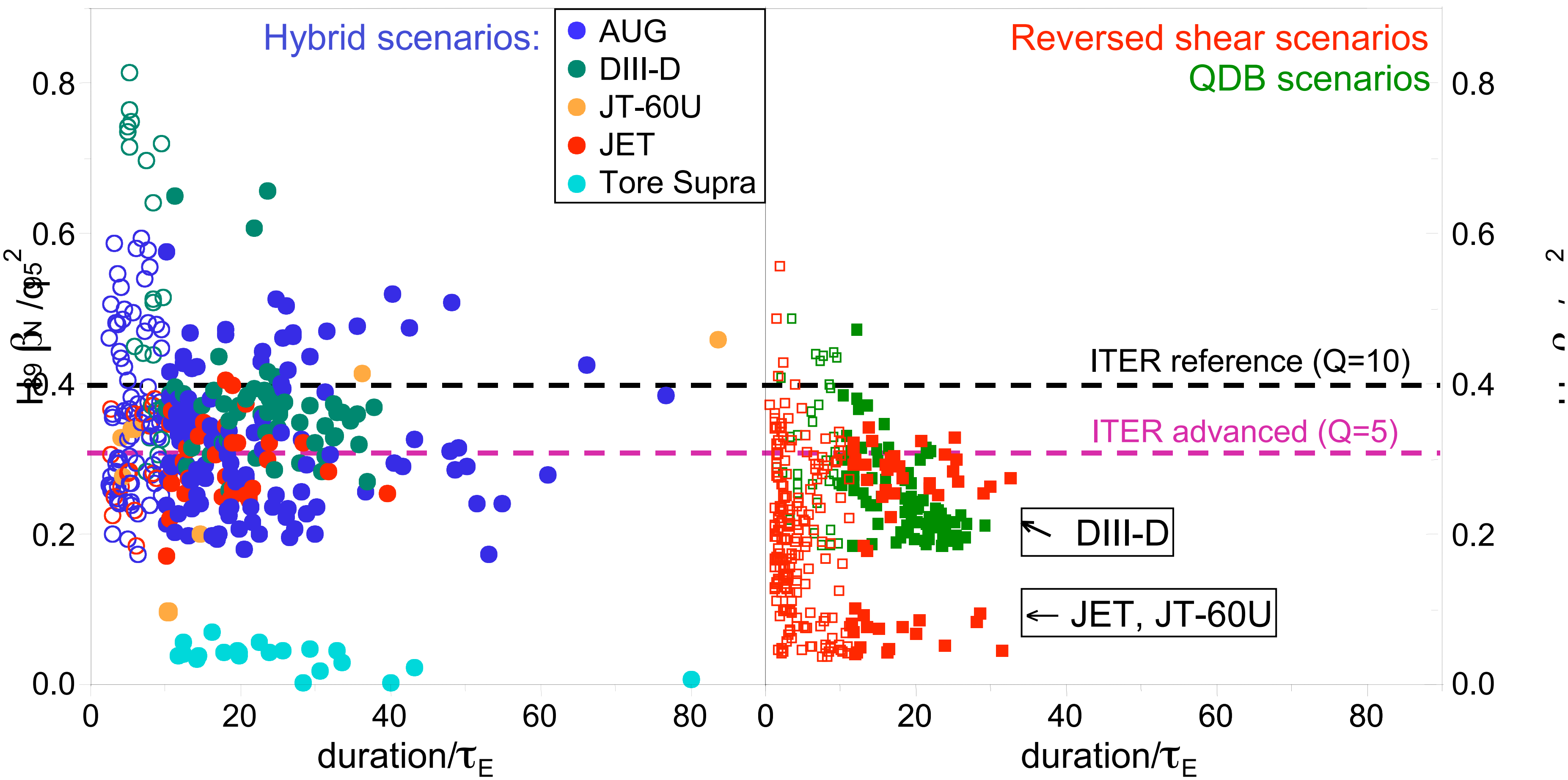
MHD High Priority areas - NTMs ECCD Feedback



- **Proposed 20 MW, 170 GHz, "high launch" ITER system** adequate to mitigate either or both the 3/2 and 2/1 NTMs
  - good alignment and modulation should keep both islands small
- Removing the metastable condition with unmodulated ECCD is problematic

Multiple Machine Results Point the Way To Very Long Pulse or Steady-State Operating Modes in ITER

Presented at the IAEA 2004



Progress In The ITER Physics Basis Was Published! 9000 Downloads!!

Volume 47, Number 6, June 2007

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PROGRESS IN THE ITER PHYSICS BASIS

ITPA Has Participated in the ITER Design Review

- ITPA participation invited by PDDG Norbert Holtkamp in October, 2006
- Working Group was formed to prepare a strawman set of issue cards
- Strawman set of issue cards went to the Topical Groups
- Topical Groups considered them in their fall 2006 meetings.
  - Altered the strawman set
  - Recommended deletions, consolidations, and additions
  - Issue Card set sent to ITPA CC in special meeting after IAEA 2006
  - ITPA CC made alterations, deletions, and and sent that list to ITER-IT
- Many ITPA members are participated in the Design Review
- Topical Group meetings in the spring of 2007 used to discuss design review issues as framed by the ITER Design Review Working Groups
- Joint Experiment work acquired an immediate design review focus.

ITPA Website http://itpa.ipp.mpg.de/

ITPA

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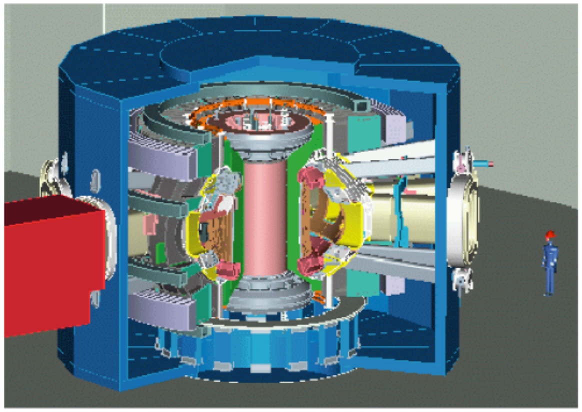
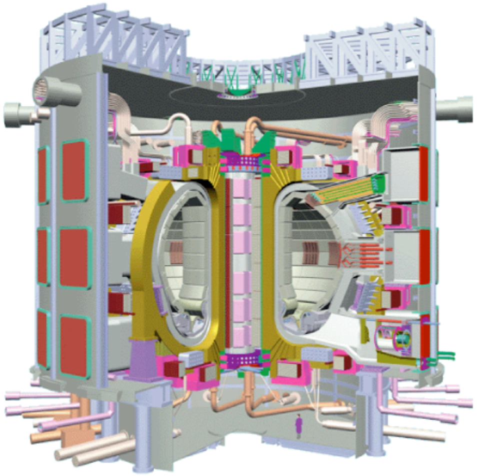
Welcome to the ITPA WWW site





The **I**nternational **T**okamak **P**hysics **A**ctivity **(ITPA)** aims at cooperation in development of the physics basis for burning tokamak plasmas. The ITPA continues the tokamak physics R&D activities that have been conducted on an international level for many years resulting in achievement of a broad physics basis useful for all fusion programs, for the ITER design, and for general tokamak research worldwide.