Report of ITER EG / ITPA TG on MHD, Disruption & Control

O. Gruber (IPP Garching) for the Group

- **meetings, scope of TG**
- **recommended research priorities**
- **assessment of R&D research / action list 2002 / highlights since last CC meeting**
- **international collaboration within IEA Large Tokamak and Pol. Divertor Agreements**
- **action list for 2003**
- **interaction with other ITPA TGs**

General comments

TG Meeting #2 after ITPA CC #2: 21-23 Oct 2002, IPP Garching
- in combination with IAEA FEC 2002
- 26 participants
- 2 sessions with Pedestal TG
- diagnostic needs (with A. Costley)

Meeting #3 after EPS 2003 (St. Petersburg) July 2003: 2 days

Main topics:
- β limiting MHD modes and their active control (NTMs, Kinks, RWMs)
- edge MHD stability for different ELM types
- disruptions: mitigation, halo currents, forces & heat loads, DB
- control issues & related diagnostics

Scope and Task definition, physics research areas:
as defined at ITPA CC#2
--> assessment of R&D research

Assessment of R&D research / action list 2002 / highlights: NTMs limit β with positive magnetic shear

- β_N(onset) ∝ ρ*; ν* scaling weak:
  - both for (3,2) and (2,1) NTMs (JET, AUG, DIII-D)
  - similar scaling for NTM onset and heating ramp-down experiments (AUG, JET)
  - strong hysteresis effect

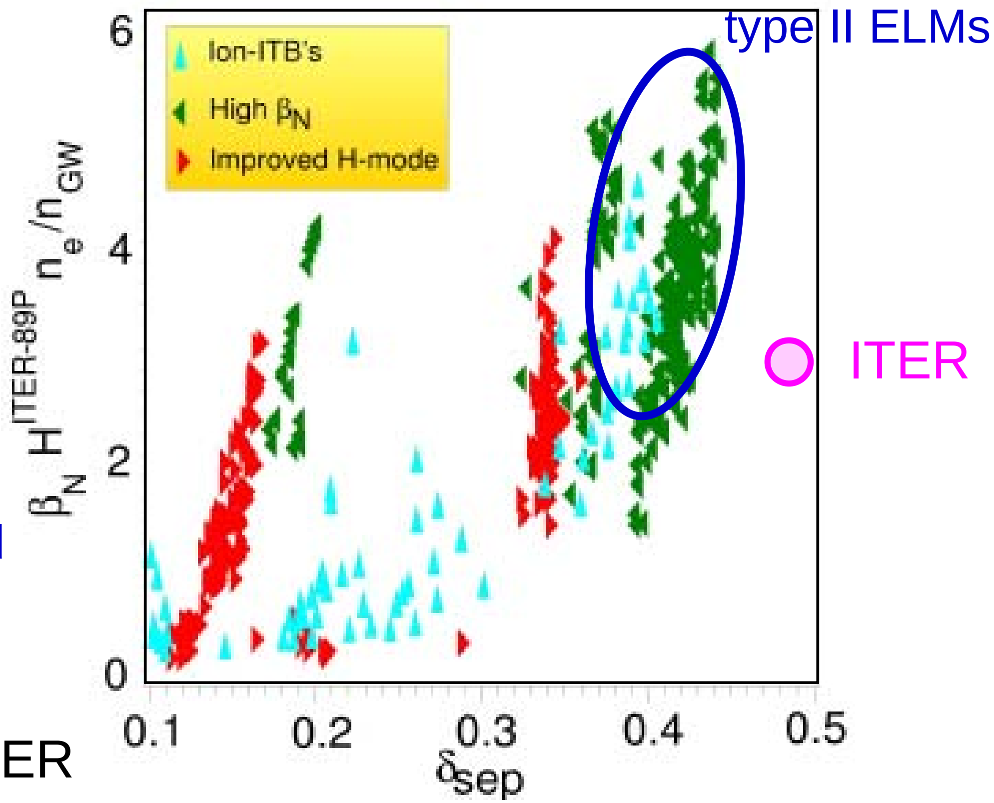
  Joint International Exp: **(2,1) onset in JET, AUG, DIII-D**

- Increase in triangularity:
  - improves edge pressure limit
  - higher β_N for same local β_p (same q_{95} at lower B_t)
  - direct influence on NTM stability

higher q_{95} over-compensated by enhanced performance

$\beta_N H_{98-P} / q_{95}^2 = 0.35$

0.2 in ITER



NTMs

- **Contributions from ST**: confirmation of existing picture

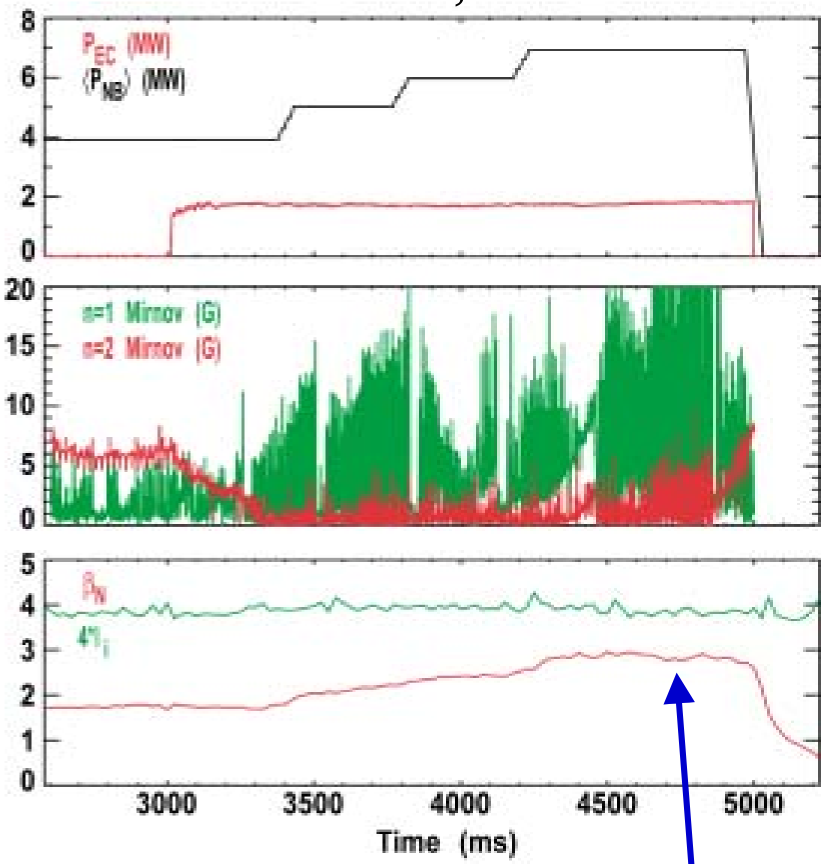
  MAST: - large seed islands trigger NTMs
  - 3,2 and 2,1 island evolution in agreement with Rutherford-equ.
  - large sawtooth region --> strong influence on confinement
  - pressure driven kink-limit: $\beta_N \leq 5.5$ by profile broadening

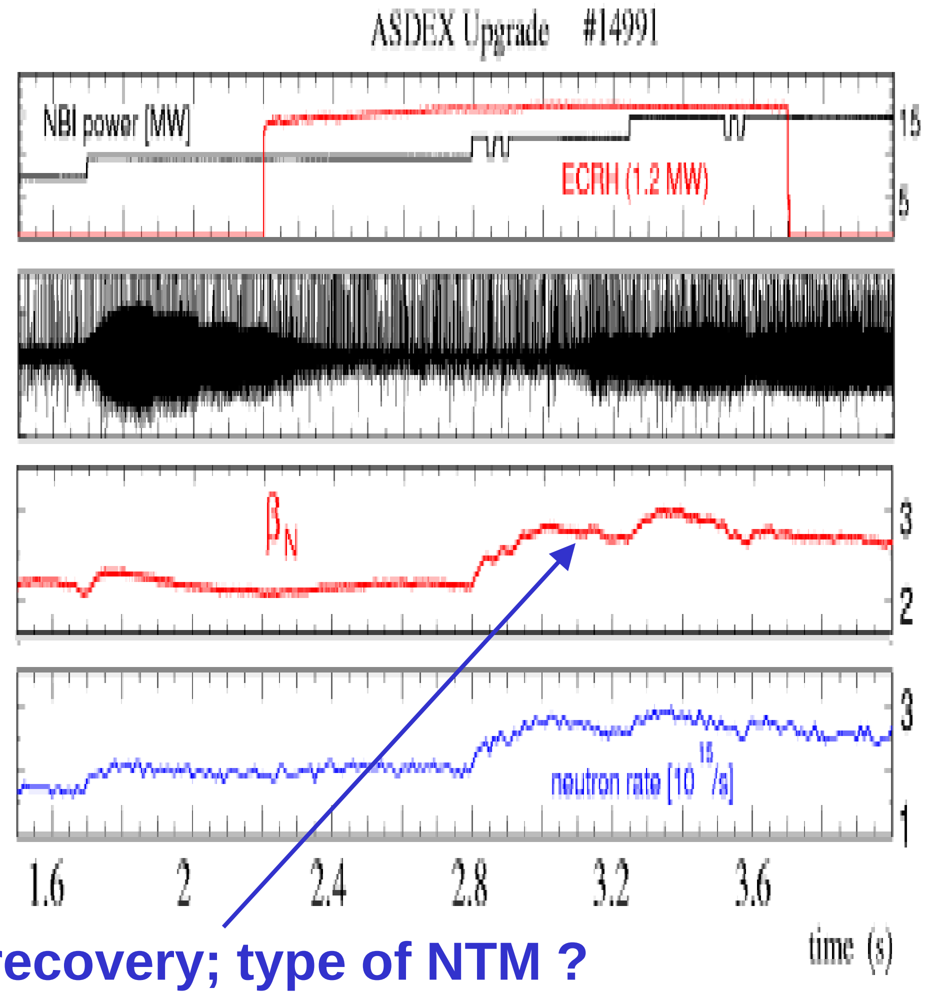
  NSTX: - β_N / l_i --> 10 by profile broadening in H-mode and high triangularity
  - $\beta_N \leq 6$, $\beta_{tor} \leq 35\%$
  - high Mach numbers M=0.3

- Influence of error fields on NTMs?

3/2 NTM stabilized by dc ECCD: increase of β

DIII-D   also 2,1 stabilised





Confinement after β-recovery; type of NTM ?

- re-occurence of NTM by mismatch between ECCD deposition and q=3/2 surface (Shafranov shift, changes in the current profile)
- feedback system needed: - radial position — DIII-D (AUG),
  - steerable mirror — JT-60U (AUG,DIII-D)
  - tunable frequency — (AUG)

Sawtooth control by ECRH / ECCD around q=1 surface

- influence on plasma energy and a-power negligible

  modelling with /Porcelli model --> ITER Feat: τ_{st} = 50 s

- reduction of seed islands for NTMs

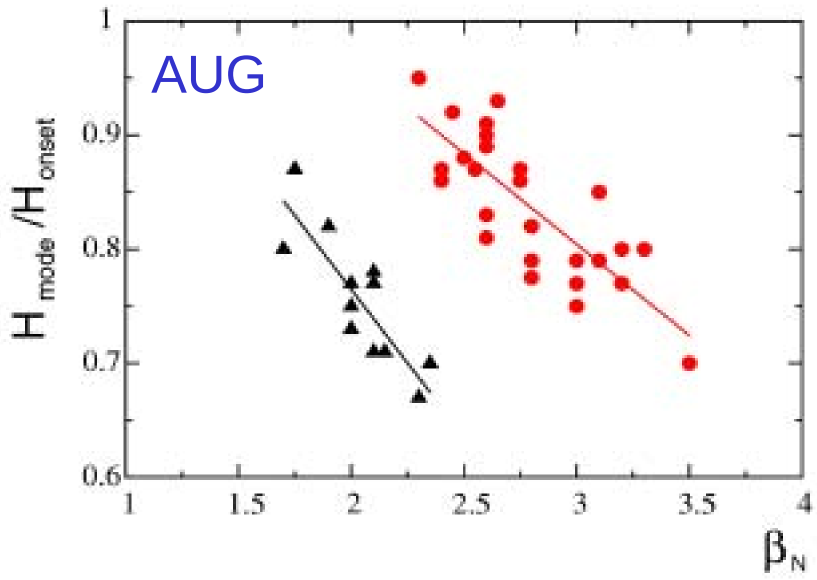
co-CD inside q=1 radius or ctr-CD outside --> sawtooth frequency enhanced

ctr-CD inside q=1 radius or co-CD outside --> sawtooth frequency reduced towards stabilisation

JT60-U (ECCD)
AUG (ECCD)
TCV (ECCD)
JET (ECCD)

Joint international experiments:

- **High confinement in spite of (3,2) NTMs:** seen on AUG and JET
  JT60-U, DIII-D ?



- Confinement improvement at higher plasma pressures !
- a regime with 'acceptable' **F**requently **I**nter **R**upted NTMs may exist for ITER

Operation with saturated NTMs possible ?

- **(2,1) onset in JET, AUG, DIII-D**

- **Halo current drive to influence MHD modes by coupling:**
  - first exp. at T10
  - check of feasibility at other exp.
  - discussion of joint exp. At next meeting

RWMs: stabilisation by plasma rotation or direct ?

DIII-D:- plasma rotation slows as β_N exceeds β_N(no wall); consistent with ideal MH

- RWM grows when rotation drops below crit. value

Ω_{crit} a few percent of $\Omega_{A,tor}$,

- marginally stable RWM amplifies plasma response to n=1 error field,
(small damping rate or drag)

- active control reduces amplified error field response:

- stabilisation is consequence of sustained plasma rotation
- feedback or pre-programmed error correction currents --> same result
- direct RWM hard to demonstrate

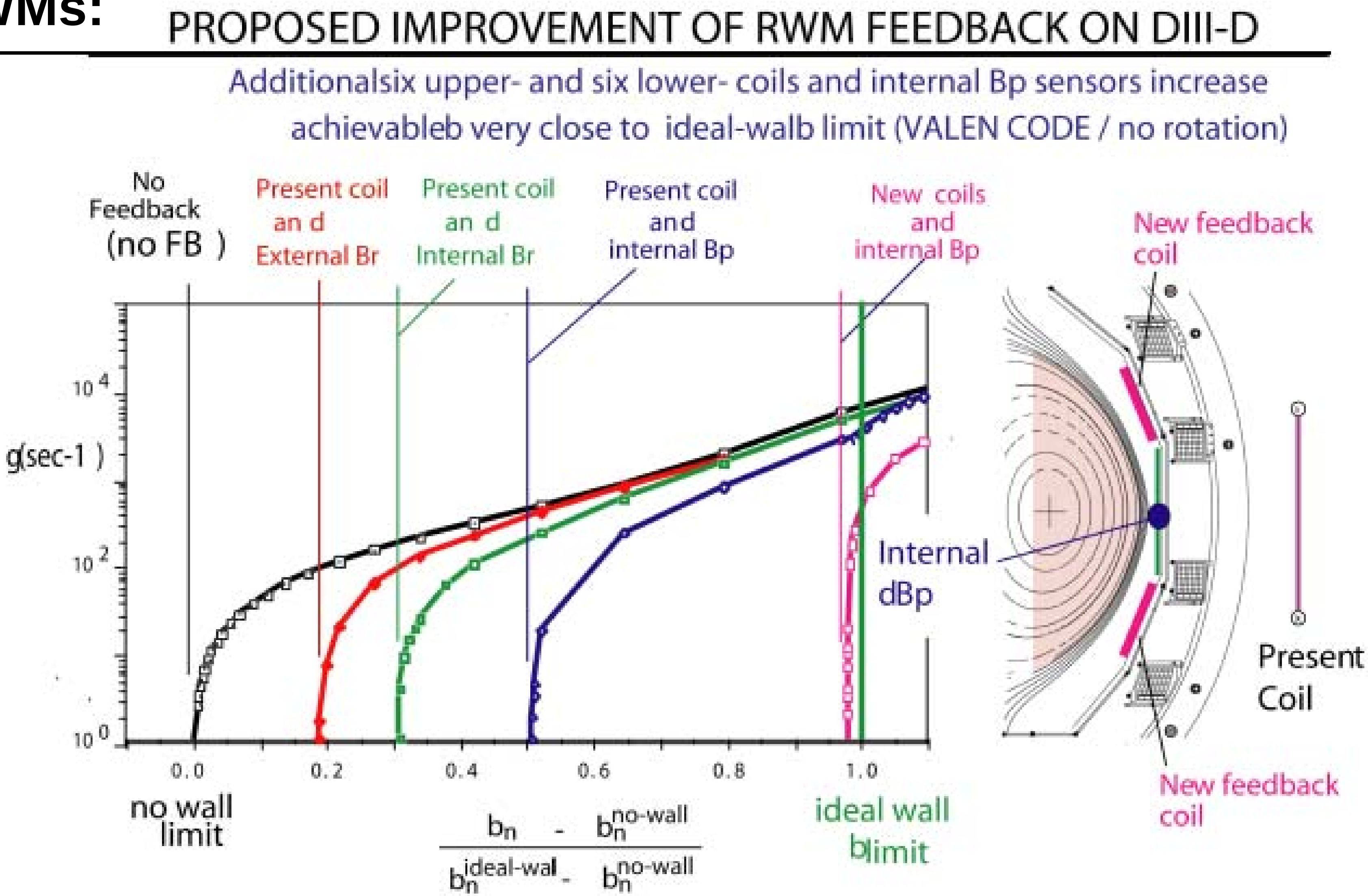
- achieved: β_N up to 1.5 β_N(no wall) for several confinement times
  β_N up to β_N(ideal wall) transiently
- agreement with VALEN / DCONN

Modelling for ITER started --> - strong stabilising effect from CFC tiles
- β_N up to 3.6

* better reference equilibria needed (action for 2003)

Analytical models (with conformal wall surface) availlable

RWMs:



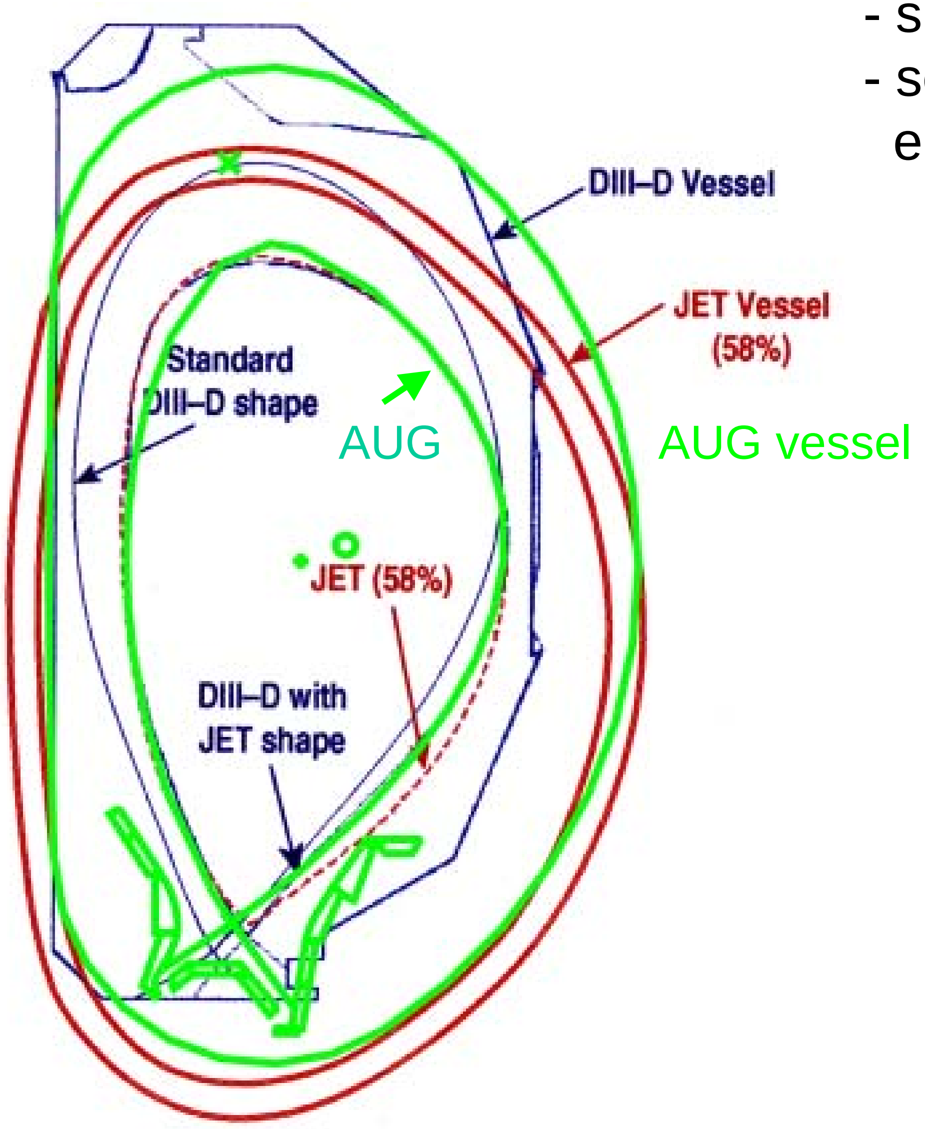
FIRE: - RWM active coil embedded in port plugs
- resonant error field minimization
- rotation maximisation (a few kHz)
- active control

JFT-2M: influence of ferritic steel

Joint international experiments:

Kink / RWM stability (JET, DIII-D, AUG**):** - influence of wall distance

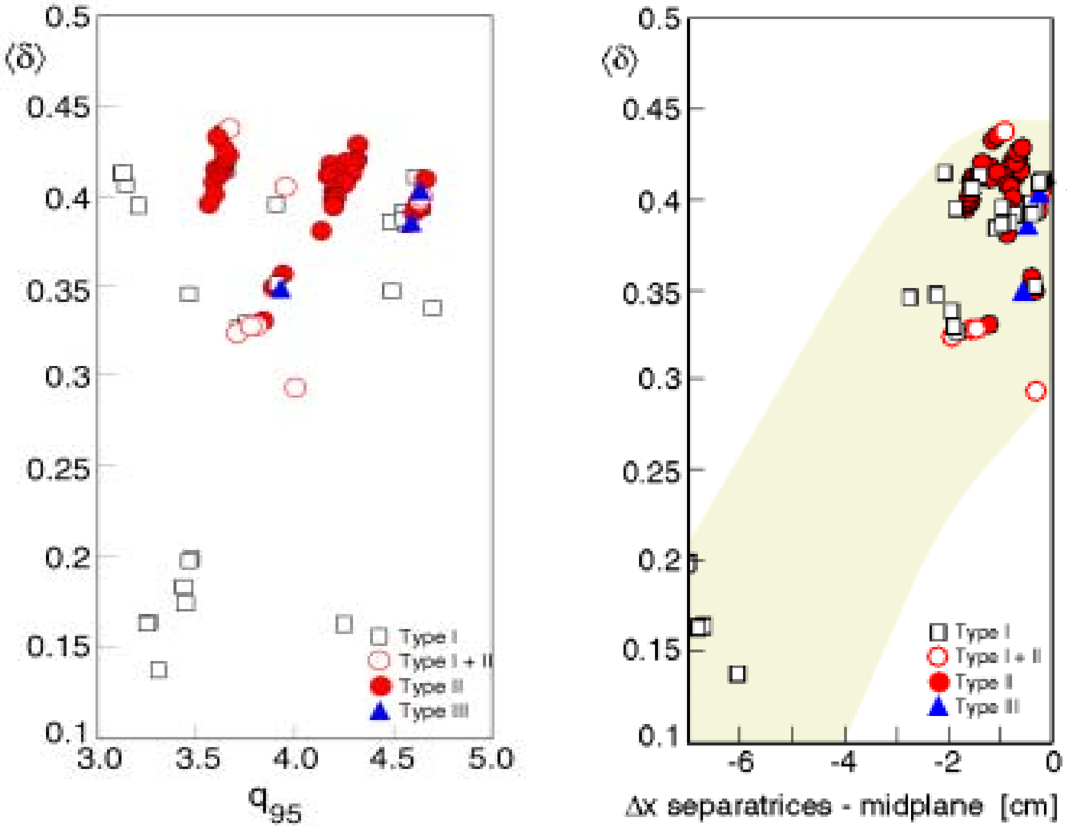
- size scaling of critical rotation frequ.
- sensitivity of high-beta plasmas to error fields



Extension of operational regime for type II ELMs

ASDEX Upgrade, DIII-D, JT60-U, JET, ALC C-Mod

similar at JT60-U



difference in ELM types: density

- **high edge shear ⇔ ELM suppression due to a change in edge stability**
  - **q > 3.5**
  - **closeness to double null essential** (triangularity connected)
  - **high edge density**

    supportive due to higher pedestal collisionality --> reduced edge BS

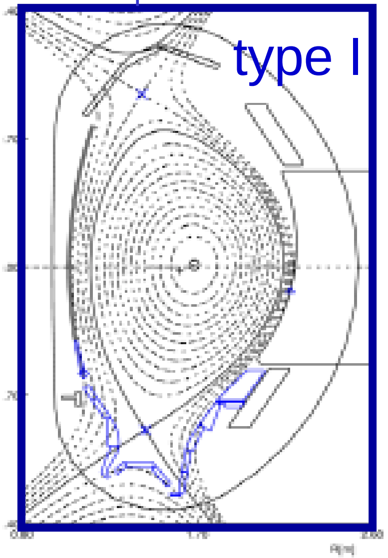
    (ν^* = 1±0.5; comparable in type I ELMs)

Edge MHD stability at transition from type I→II ELMs

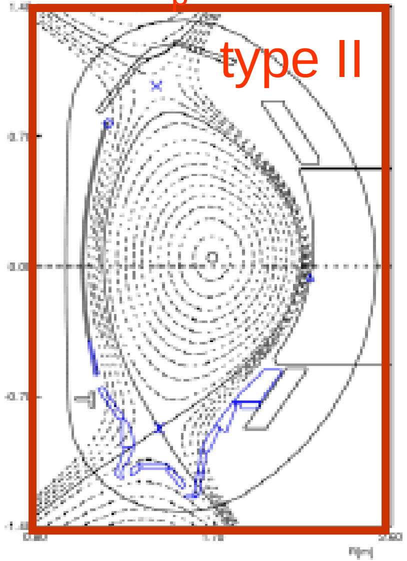
- slightly different configuration
- same T and n profiles / gradients

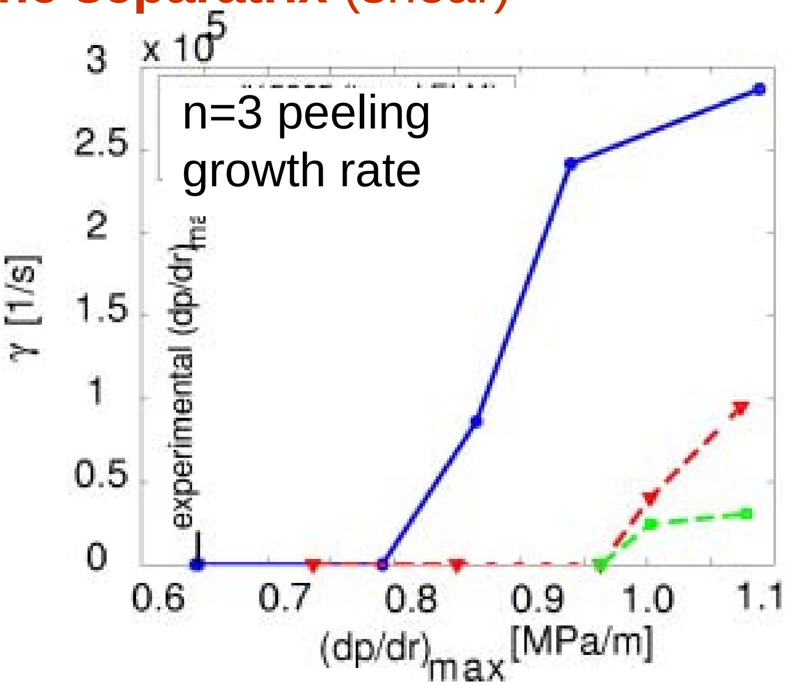
- **at 1. stability limit of ballooning** modes (high shear & ν*)
- **low n peeling modes more stable** (high shear ← low bootstrap current)
- **eigenfunction for high n peelings localised to the separatrix** (shear)

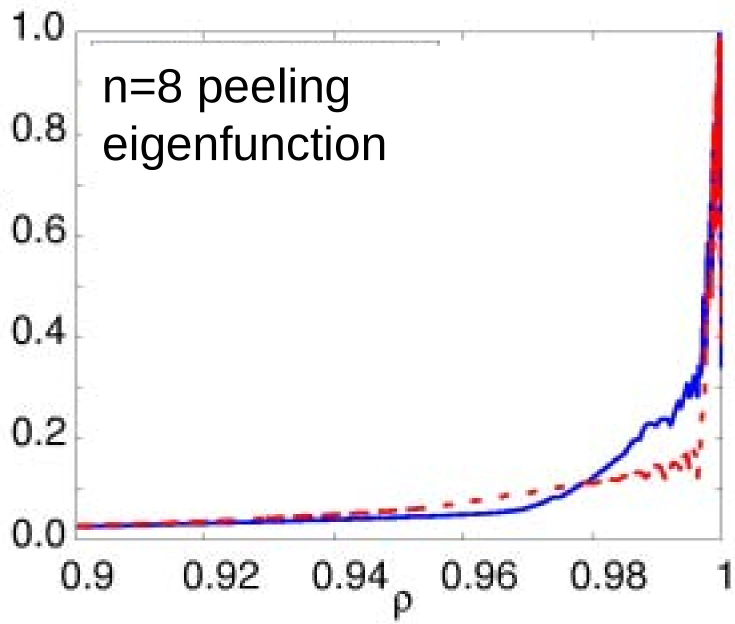
SN Δx_p = 2.2 cm



more DN Δx_p = 1.0 cm



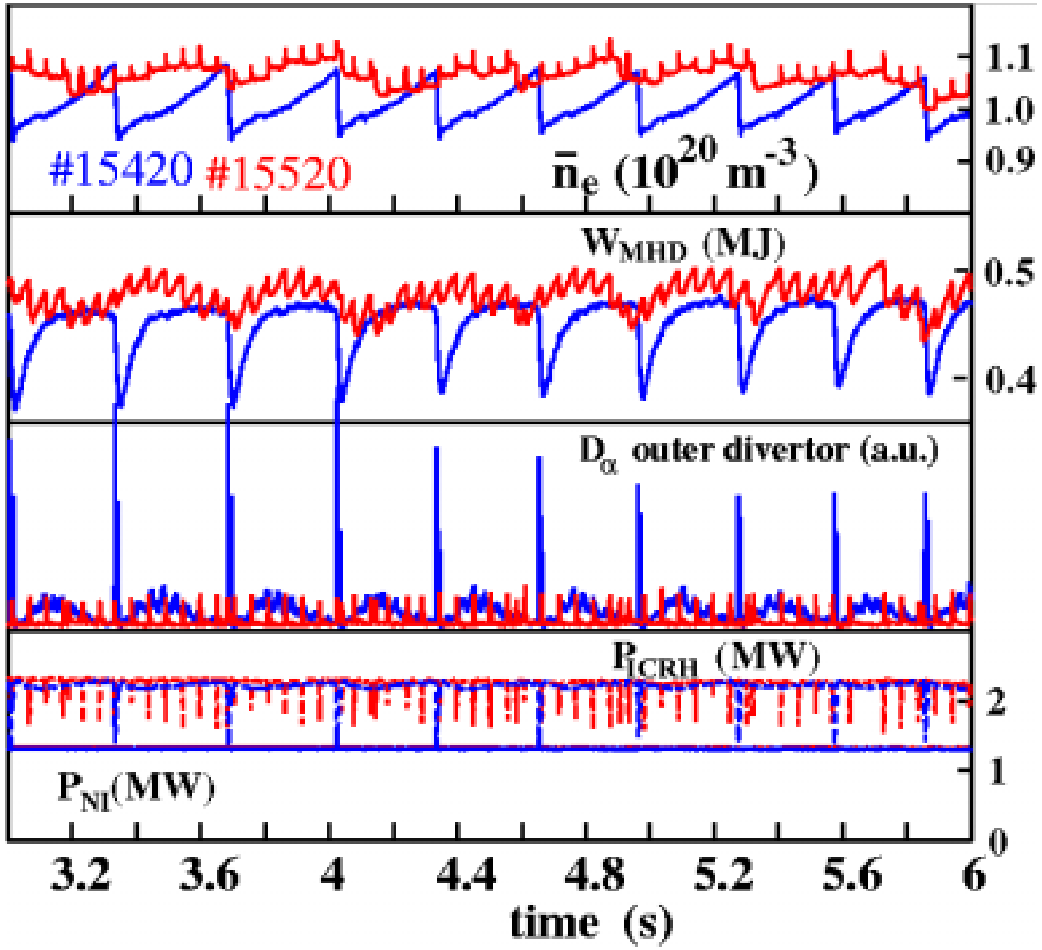




Active ELM control

Pellet injection (AUG)

- reference discharge just with type I / compound ELMs at 3 Hz
- each small pellet with shallow penetration ($< 10^{20}$ particles, 600 m/s) triggers a type I ELM
- repetition time to 20 Hz enhanced



Oscillating edge currents (TCV)

- vertical oscillations induced by position control
- type III ELM frequency adapts

Disruptions: mitigation

Killer pellets: - cooling by ionization, dilution, radiation -> thermal fluxes reduced
- faster current quench -> lower halo current & force load
- but: often runaways observed (JT-60U, DIII-D, AUG) **!**
- cryogenic system not suitable in stand-by **!**

Strong gas puff superior to killer pellet

- simpler, fast system, Ne / Ar / Kr

DIII-D: - reservoir with 70 bar, 4 10^{22} atoms, but p(jet) < p(plasma)
- ten-fold increase in n_e up to > 10^{22} m^{-3}
- **no runaways due to high electron density**
- radiation can be controlled by hydrogen additions

AUG: - 120 mbar l ≡ 4 10^{21} atoms

Result: **- fast quench --> reduction of Δz, I_h, force down to 30%**
- reduction of heat loads due to radiation down to 30%

Further exp. at JT60-U, JET, TEXTOR

Disruptions:

Fastest current quenches in RS discharges

- shortest decay times are independent from pre-disruption currents
- RS plasmas have the lowest li (--> 0.5)
- clear documentation from JT60-U

Asymmetric halo currents ⇔ horizontal force

JET: large horizontal movement of 7 mm

AUG: horizontal movement (0.3 mm) and forces much smaller

--> vessel support, stiffness, ...

Other experiments ?

DINA simulations --> predictions

DINA could be the basis of a plasma control simulator (PSI):

- add program modules and packages
- test of DINA code with experiments:
  DIII-D, analysis of JT-60U presented, TCV and AUG in progress
- simulation of ITER VDEs and disruptions presented

3d-modelling of toroidal asymmetries has started:

- CEMM: M3D (close ideal flux surface), NIMROD;
- include pressureless halo plasma and wall currents
- experts participated in TG meeting (Jardin, Paccagnella)

Disruptions: Databank

- J. Wesley will be responsible (support from GA ?)
- new set-up (formats as in other DBs)
- contact persons will define content
- decision on scalar and vector (space, time) variables

- results from simulations should enter
- DB should give platform for testing of disruption simulators

- urgent issues, as heat load on targets, have to be clarified in parallel

Control and Diagnostics

Control: TCV reported on PF control and transport simulations using MHD and „fitting“ mode of DINA

Diagnostics:

- participation of O. Gruber in one session of the March meetings at GA
- requirements for NTM control provided by AUG team (M. Maraschek)
- requirements for RWM control:
  first estimates from ITER IT (Gribov)
  next step will be provided by DIII-D (E. Strait responsible)
-

Actions in 2003

- **Publications or conference contributions: not decided.**
- **NTM stabilisation requirements for ITER, FIRE:**
  - demonstration of NTM stabilisation (CD, sawtooth control, FIR modes)
  - presently no advantage of ac compared to dc CD, but ...
    in ITER: smaller seed island size plausible ($w_{seed}/a <<1$)
    slow plasma rotation $\Rightarrow$ modulation may be needed
    CD in X-point not effective (not necessarily 100%)
  - needed I_{CD} within islands = missing bootstrap current:
    differences due to different kinetic profiles,
    --> P_{ECCD}, frequency, mirror angles
- **RWM**:
  - better reference equilibria needed
  - investigation of dissipation mechanism (sound waves, neocl. rotation damping)
  - influence of momentum input & direct feedback (NI+ICRH, balanced beams)
- **ELMs**:
  - definition and evaluation of DB for stability calculations
  - edge stability calculations in different ELM regimes
- **Disruptions**:
  - development of DB

Interaction with other TGs

Pedestal TG:

- Input parameters to pedestal DB needed specific for MHD stability
  (collisionality, edge bootstrap current, magnetic shear, ω_e*, ...)
- common strategy to evaluate edge BS current
  (local Bp measurements, estimate from neoclassics and ∇p)

Transport TGs:

- confinement in beta recovered feedback stabilised NTM discharges

Steady-State & CD TG:

- evaluation of requirements (P, injection angle, frequency, ...)
  for ECCD stabilisation of neoclassical tearings
- MHD limits of conventional and advanced scenarios
  for hybrid or steady-state operation
- control simulations and PF scenarios for steady-state advanced scenarios

Divertor TG:

- heat load during disruptions on walls and targets
- impurity production at high fluxes
- penetration and radiation (KPRAD / DIII-D)
- modular code packages have to be included in disruption modelling

Contact Persons

MHD, D & C

→ Pedestal TG:	H. Wilson
→ Steady-State & CD TG:	C. Gormezzano
→ Divertor TG:	A. Loarte
→ Transport TG	F. Ryter
→ ITB TG:	(E. Doyle)
→ Diagnostic TG:	A. Costley

Disruption Databank:	J. Wesley
JET	
JT60-U	
DIII-D	
ASDEX Upgrade	G. Pautasso
Alcator C-Mod	R. Granetz
Compass	
MAST	
NSTX	

Tokamak Physics Basis

- **Update of ITER physics basis**
- significant progress in experimental, theoretical and modelling work towards BPXs
- providing of methodologies to project the characteristics of BPXs

- reasons for the aim of this joint undertaking
- why not in 2004 or ?
- no standard steady-state scenario comparable with the conventional H-mode standard scenario

- **Time schedule**

......submission to NF Dec 2003

- ITER Physics Basis took more than 2 years:
  - after the first sumission to NF still a lot of changes have been made;
  - at least 2 EG meetings were devoted to this writing
- a large central team has coordinated and formulated most of the manuscript
- see problems of ITB TG to finish an extended manuscript

$\Rightarrow$ **stretching of schedule by a factor of 2 needed**