US MHD Control workshop: 23-25 Nov 2008, Austen, Texas.

# The New EU MHD Topical Group: Complementarity and collaboration with the US programme on MHD


Richard Buttery [1] and Piero Martin [2]

*(1) UKAEA Culham Science Centre, Abingdon, Oxon OX14 3DB, UK*
*(2) Consorzio RFX – Associazione Euratom-ENEA per la Fusione, Padova, Italy*


***Thanks to many colleagues for providing input and information.***

# New structure in the EU Fusion Programme

- **European Fusion Development Agency** seeks to boost coordination in the EU programme:
  - Joint exploitation and development of facilities and common tools
    - ***More centrally coordinated projects with 'calls' and 'tasks'***
  - New topical groups set up:
    - **Diagnostics:** T. Donne, M Beurskens, A Murari
    - **Transport:** C. Hidalgo, C. Angioni, C. Bourdelle
    - **MHD:** P. Martin, R. Buttery
    - **Heating and Current drive:** A. Becoulet
    - **Materials:** S. Dudarev, M. Rieth
  - …and task forces continue:
    - **ITM:** P. Strand, L.G. Erickson. M. Romanelli
    - **PWI:** J. Roth, E. Tsitrone

***These "support EFDA" in coordinating implementation of its programme***

# EFDA missions

Goal: Development of plasma scenarios for ITER and DEMO

**Basis of 5 working groups set up under the MHD TG**

**Missions:**

- Burning plasmas => Fast Particles
- Reliability of tokamak operation => Disruptions, Tearing Modes
- Compatibility of plasma scenarios with first wall => ELMs
- Long pulse and steady state operation => RWMs
- Predicting performance (All MHD)

**Theory & integrated modelling**

=> MHD: basic understanding of key phenomena

# The EU MHD* Topical group

**actually "Plasma Stability and Control" group*

- Aim to focus on "**value added**" activities:
  - Getting experts together to identify priorities, avoid gaps & plan complementary work
  - Joint studies – codes and experiments
  - Knowledge base and advice to EFDA
  - Forming consensus on issues and needs
  - Strategic focus & ***reference point for collaborations***

***In this talk we outline research priorities, and ideas for <u>complementary</u> or <u>collaborative</u> work with our US partners…***

- ***Consider as tool to implement and enhance ITPA activities***

# Contents

Summarise work under our five groups:

- Disruptions
- Fast Particle
- Tearing
- ELMs
- RWMs & high β

**Which aspects benefit from joint or complementary studies?**

- ***Especially: identify new initiatives***

**Are there areas where closer joint work or projects might be useful?**

- Outputs:
  - We should try to pick out **useful joint studies** on above themes

# Contents

Summarise work under our five groups:

- **Disruptions:** Valeria Riccardo (UK), Gabriella Pautasso (IPP)
- **Fast Particle:** Simon Pinches (UK), Phillip Lauber (IPP)
- **Tearing:** Patrick Maget (CEA), Valentin Igochine (IPP)
- **ELMs:** Andrew Kirk (UK), Marina Becoulet (CEA)
- **RWMs & high β:** Tim Hender (UK), Paolo Buratti (ENEA)

- Outputs:
  - We should try to pick out **useful joint studies** on above themes
  - ***Flag areas to pursue with me or above people, and we will set up relevant contacts***

***Number 1 MHD issue to push in Europe***

# 1. Disruptions

EU focus on:

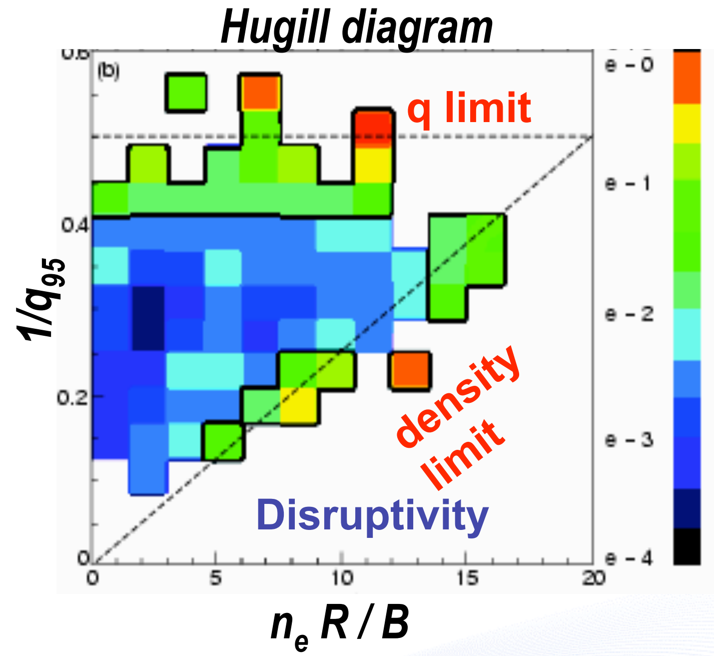
- Anticipating/detecting disruptions
- Simulating and predicting VDEs & halos
- Runaway generation, including with massive gas
- Imaging & impurity diagnosis
- Disruption database

[courtesy P. De Vries]

New ITPA MDC-17

# Physics Based Disruption Avoidance

- JET's best disruption avoidance rate is 6%
  - With all shots made in advance and T used
  - Rate increases near operational limits →



[courtesy P. De Vries]

New ITPA MDC-17

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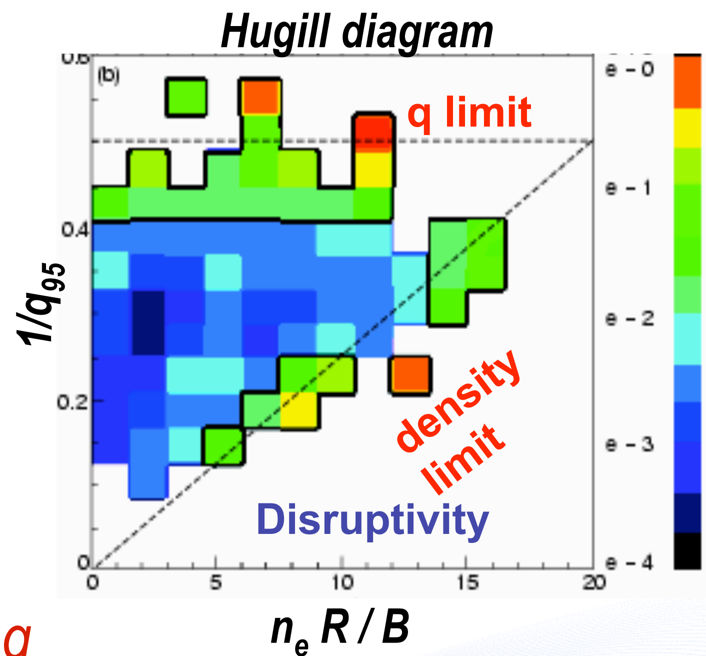
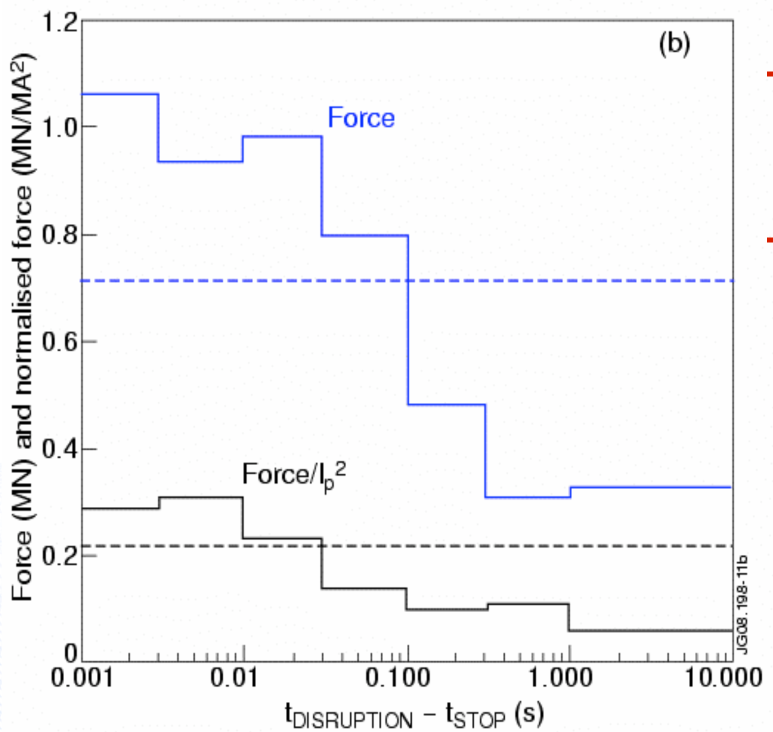



***Key is detecting event in time:***




- *Allow time to mitigate*
- *Simple sensing & mitigation techniques can be applied*

Need to test detection or anticipation methods on various devices:

- ***Physics based approaches seem most promising***

[courtesy V. Riccardo and G Pautasso]

# Halo current and VDE modelling

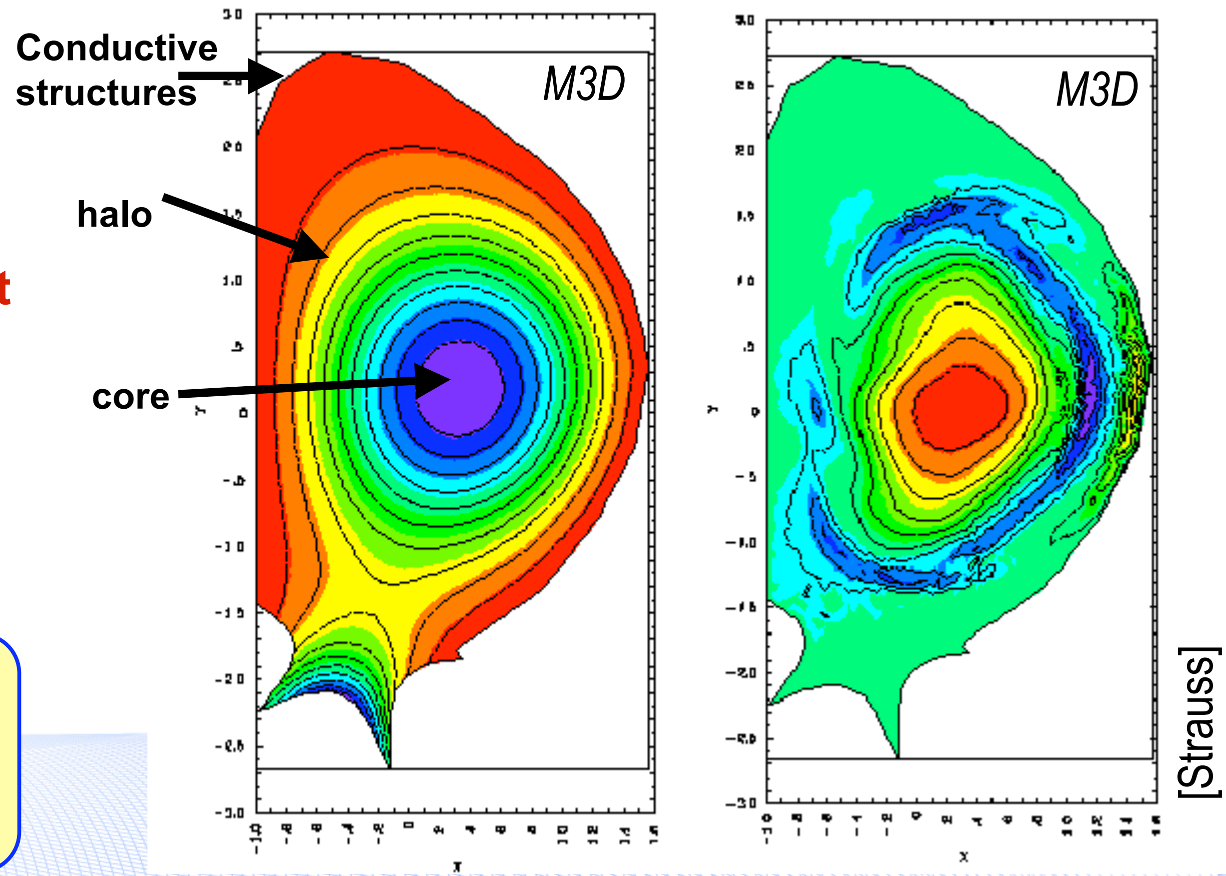
***Halo currents give rise to main forces on in-vessel components***

- **Extent of region affected**
- **Average and peak current densities**

→ ***Impacts engineering design and depends on simulation assumptions***

***Joint EU/US work on 3D simulations (M3D) has started and we are keen for this to continue and expand.***

**Poloidal flux:**




**2D** **3D**

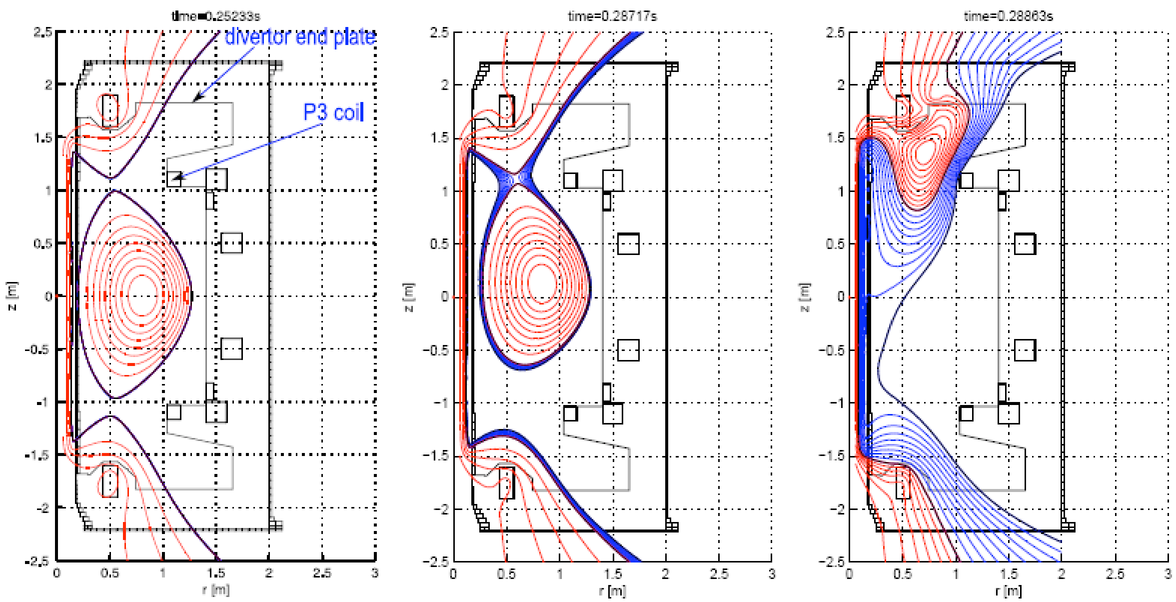
[courtesy V. Riccardo and G Pautasso]

# VDE simulation

## EFDA MHD – short term plans

Validate further the use of DINA, by carrying out simulations of ASDEX-Upgrade disruptions and compare them with observations

(Also MAST VDEs are being simulated with DINA)




## EFDA – long term plans

Develop EU codes able to simulate disruptions and fitting within the suite of codes developed by ITM – in stages:

- Axisymmetric VDE with halo model
- Include impurities
- Go 3D

**US collaboration valuable here to benchmark codes as they develop and compare physics trends** ***– your comments, views and ideas are most welcome***

[courtesy V. Riccardo and G Pautasso] **New ITPA MDC-16**

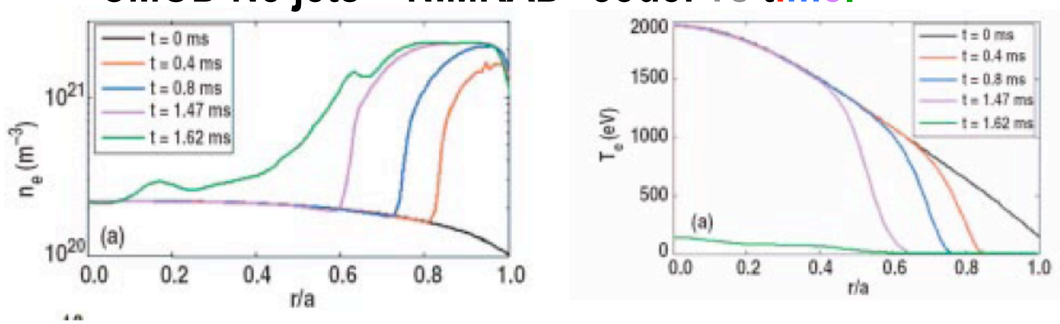
# Runaway electrons

- Explore runaway generation threshold from experimental data
  - (i.e. plug in the Fulop et al. formulas)
- Explore avalanche suppression
  - Including mid-sized devices, e.g. TEXTOR
  - Min radial field amplitude and structure from existing experiments
  - *New experiments…?*
- What parts can be included in the *International Disruption DB*?

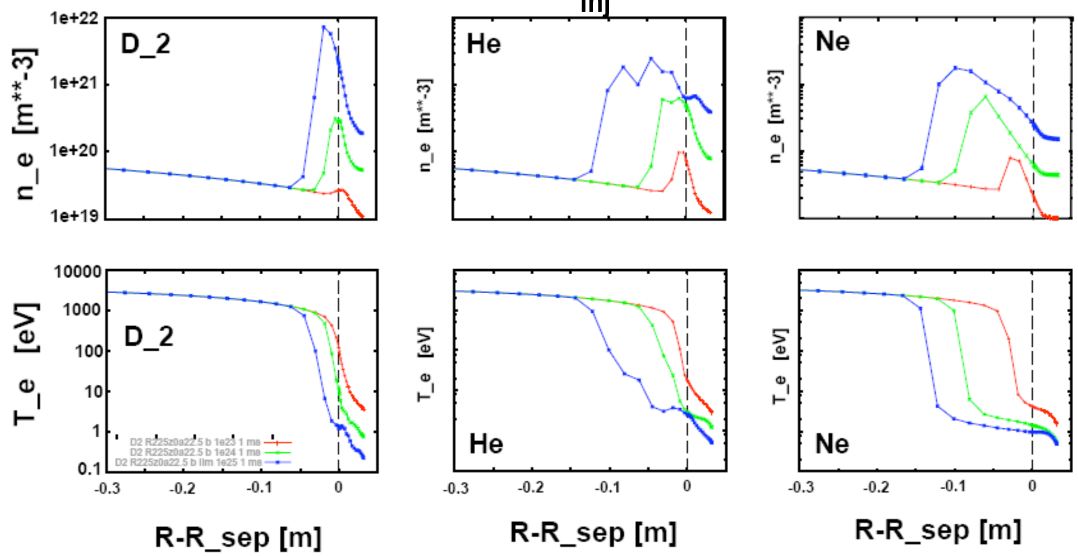
**Comparing results with US will be useful to help resolve this physics**

# Modelling ‘massive gas’ runaway mitigation

**CMOD Ne jets – NIMRAD[1] code: vs time.**




**AUG – SOLPS code[2]: $dN_{inj}/dt$ = $10^{23}$ $10^{24}$ $10^{25}$**




[[1]Izzo, PoP 15 056109, [2]Pautasso, IAEA 2008]

## Predicting ITER needs requires modelling:

- No of atoms to prevent runaway generation
- How impurity atoms penetrate core

## Coordination beneficial:

- Compare experimental behaviour
- Test common code understandings
  - ***what physics required?***
  - ***benchmarking***

# 2. Fast particle instabilities

EU focus on:

- Linear stability thresholds
- Fast ion redistribution
- Non-linear mode evolution
- Diagnosis

*Basis of field is experimental tests vs theoretical modelling*

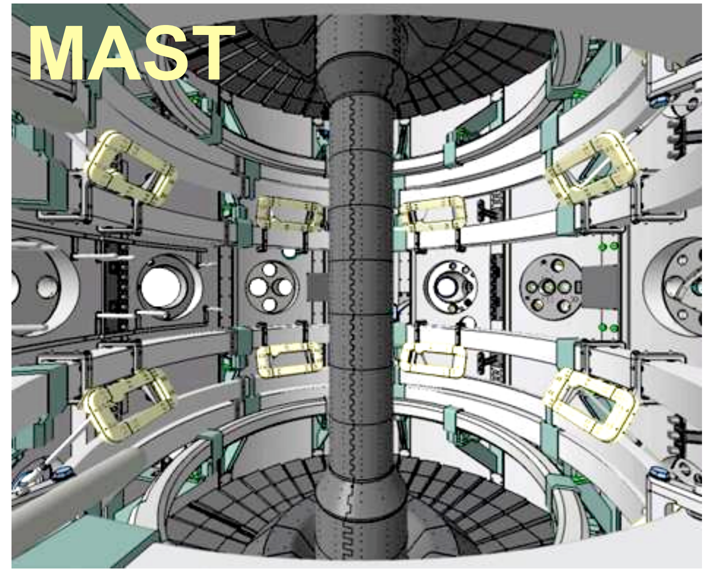
- ***…but this may become an MHD control problem!***

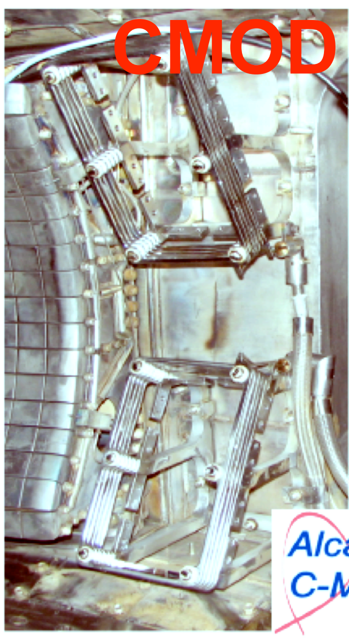
# Probing TAE stability

[courtesy S. Pinches]

## Complementary systems:

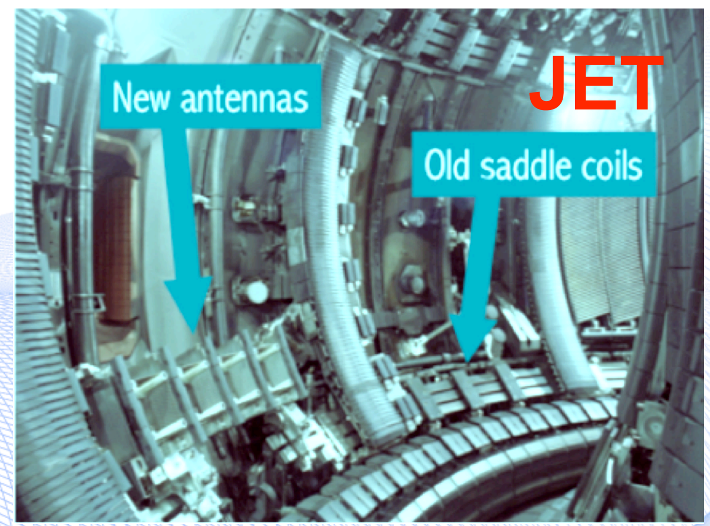
- JET: New antennae can drive $n < 30$
- MAST: $n = 1 - 3$
  - 12 coil system: 6 upper, 6 lower
  - 6 independent power supplies
- C-MOD: Intermediate $3 < n < 12$:
  - Broad spectrum centred on $n = 6$




Alcator C-Mod

- **Damping rate trends differ with different *n* modes**
  - **Independent tests of common physics models**
  - **Benchmark EU vs US codes**



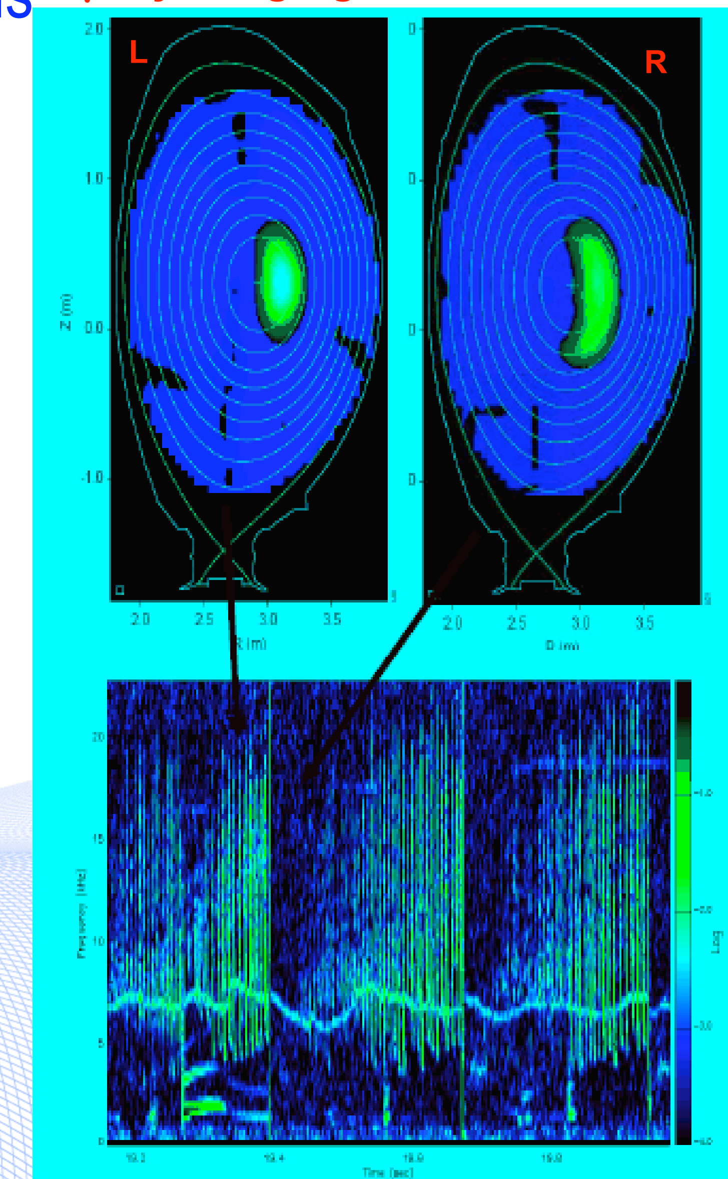

[A. Fasoli, J. Snipes]

# Fast Ion Redistribution

[courtesy S. Pinches]

- Alfvénic / MHD modes can redistribute ions
  → J profile, $\alpha$ heating, losses…
- Experiments need to isolate clear effects
  – Many good & complementary new diagnostic techniques
- **Opportunities through collaboration:**
  – Domplementary diagnostics
  – Different parameter scans
    ➢ **Build up a holistic picture of effects**
  – Share very-well-diagnosed cases to provide code-based tests of theory
  – Benchmarking codes

**$\gamma$ ray imaging: sawtooth on JET**



# 3. Tearing physics

EU focus on:

- Sawtooth Stability
- Neoclassical Tearing modes
  - Trends. Understanding.
- Control of both instabilities
  - Tools, physics, real time

# Sawtooth Control

[courtesy I. Chapman]

- **Sawtooth triggering criteria:**[1]

*Strong fast ion role in δW*

  - Resistive instability: $\pi \frac{\delta \hat{W}}{s_1} < c_\rho \frac{\rho}{r_1}$ and $\gamma_\eta > c_\eta \sqrt{\omega_{*i}\omega_{*e}}$
  - Ideal instability: $\pi \frac{\delta \hat{W}}{s_1} < -\frac{\omega_{*i}\tau_A}{2}$

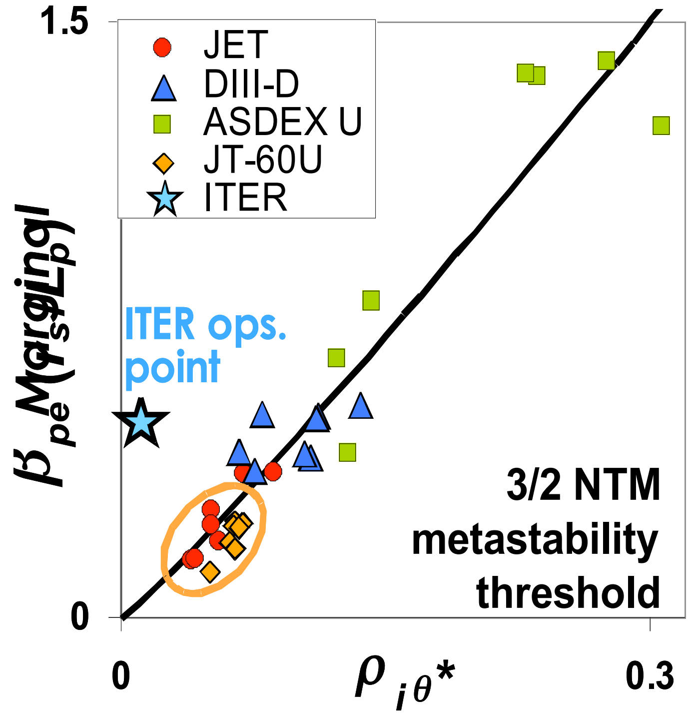
***Destabilise by reducing δW or increasing $s_1$***

- **Electron Cyclotron Current Drive**
  - *Initial TORE-SUPRA[2] results promising*
  - ***Can increasing $s_1$ work in ITER (when $\rho/r_1 \rightarrow 0$ and δW dominated by fast ions)?***
- **Ion Cyclotron Current Drive**
  - ***But control is mainly due to fast ion effects[3]***
  - *Experimental verification needed – ICCD in ITER will be small*
- **Neutral Beam Heating**
  - *JET, AUG and MAST show off-axis NBI destabilises sawteeth (Chapman et al)*
  - ***Verify with systematic tilting of beams? In presence of core fast ions?***

[[1]Porcelli et al, PPCF, 38, 2163 (1996), [2]Lennholm, [3]Graves]

# Neoclassical Tearing Modes

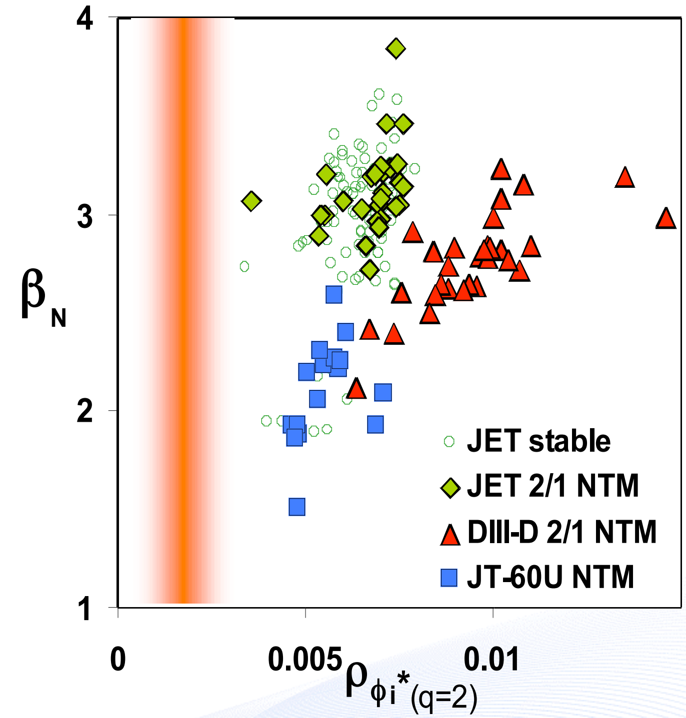
- Strong collaboration over many years
  - Eg 3/2 NTM metastable thresholds→




[Buttery, IAEA 2008]

# Neoclassical Tearing Modes

- Strong collaboration over many years
  - Eg 3/2 NTM metastable thresholds
  - **More recently on hybrid β limits→**
    - *Some puzzles here…*
- **Key issues now are:**
  - Understanding extrapolation to ITER
    - $\rho^*$, rotation, error fields, q, fast ions
  - Resolving basic physics
    - Small island effects, mode triggering, rotation role, error field interaction
  - Demonstrating control algorithms




[Buttery, IAEA 2008]

# Neoclassical Tearing Modes

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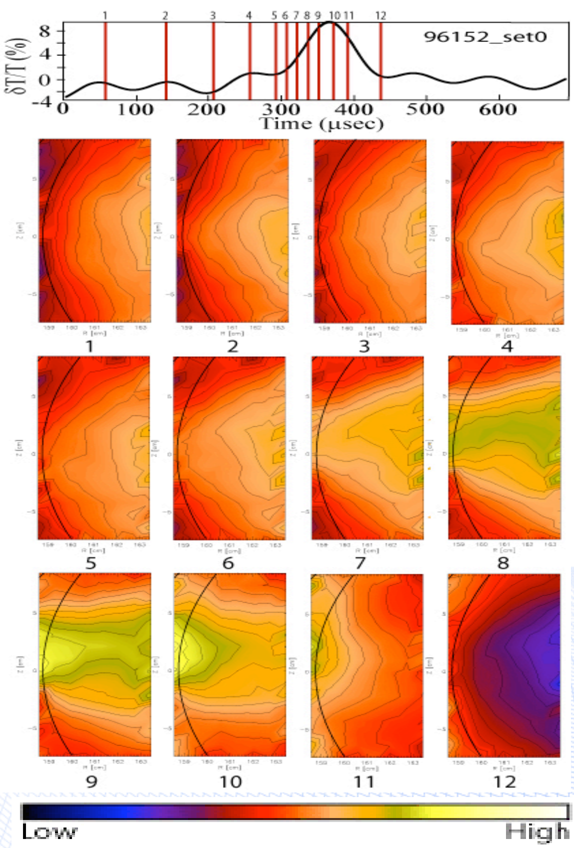
  - Demonstrating control algorithms

**Complementary strong research capabilities:**

- Torque balance & torque-free operation
- Error field harmonics cf low error field operation
- Fast particles & ECCD
- Profile diagnostics: MSE, HRTS, ECE, 2d imaging…

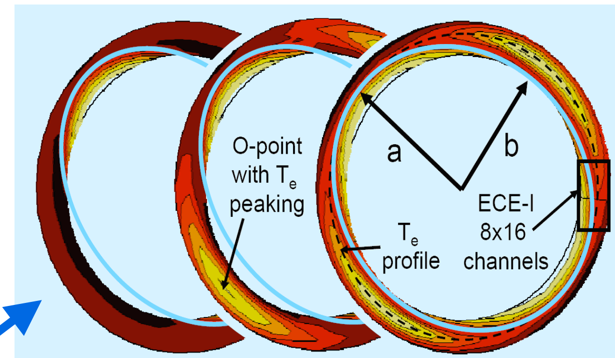
# Next steps: understanding non-linear phase

- Work progressing through codes and diagnostics, e.g.:
  - Multi-time HRTS on MAST
  - Or ECE on TEXTOR…

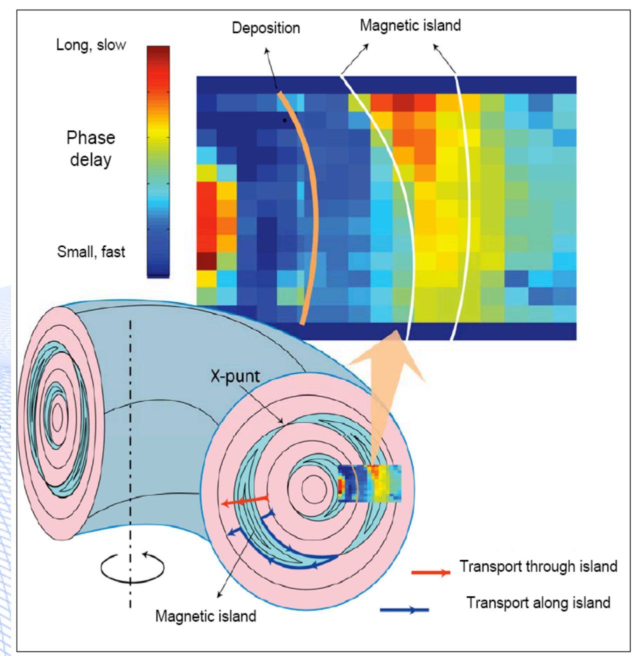



*Sawtooth crash*

*Island dynamics visualisation*




*Heat pulse propagation through islands*




[Park et al.]

*New collaborative group under IO: Max Fenstermacher coordinating collaborative work on this*

# 4. ELMs

EU focus on:

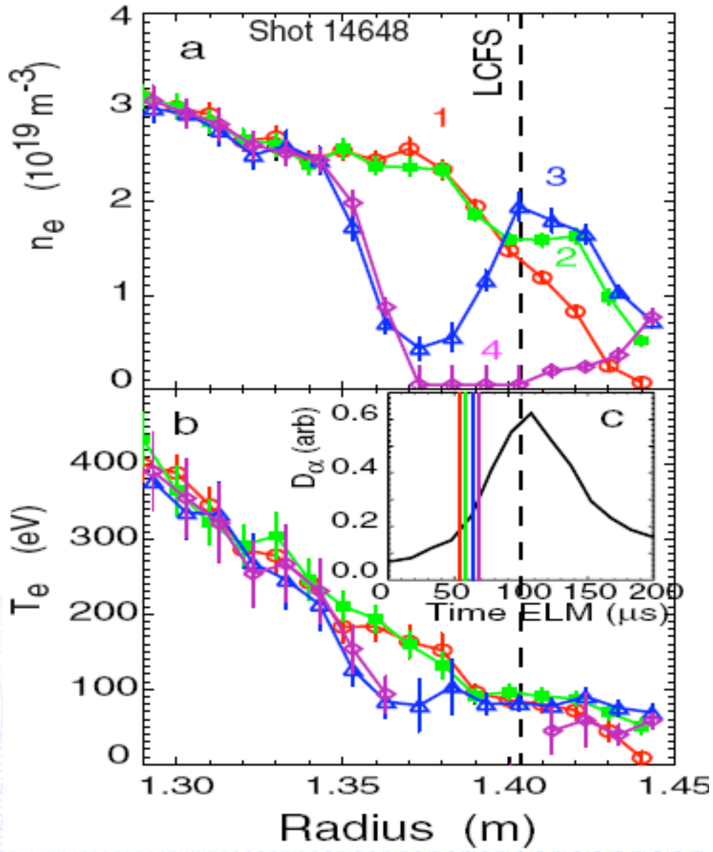
- Non-linear understanding of the ELM size & stability
- Action of mitigation techniques
  - RMPs, pellets, kicks
- Better diagnosis

***Complementary work across devices an essential part of resolving physics of RMP interaction***

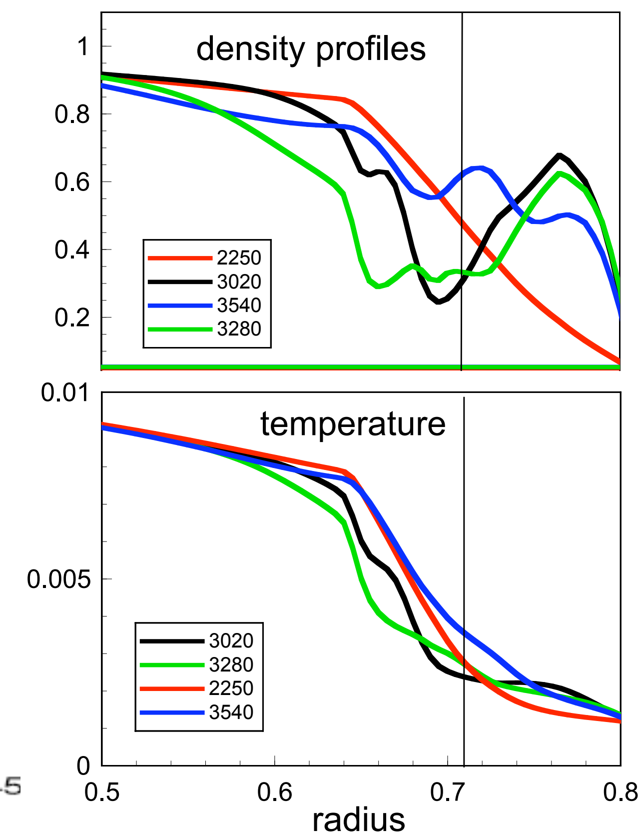
# Non linear ELM understanding

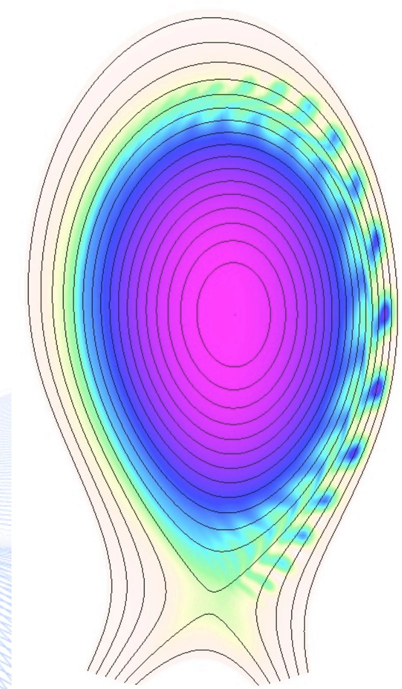
- A key focus is to understand ELM size and its dependencies
  - Compare different regimes and benchmark code understanding

MAST (A. Kirk)



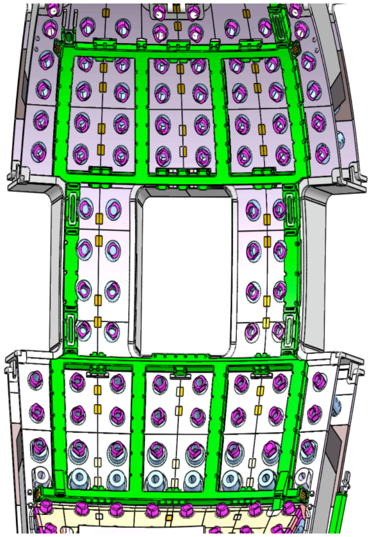

JOREK code (not MAST shape /size)



[courtesy M. Becoulet] **ITPA PEP 19,23,25**

# ELM RMP understanding



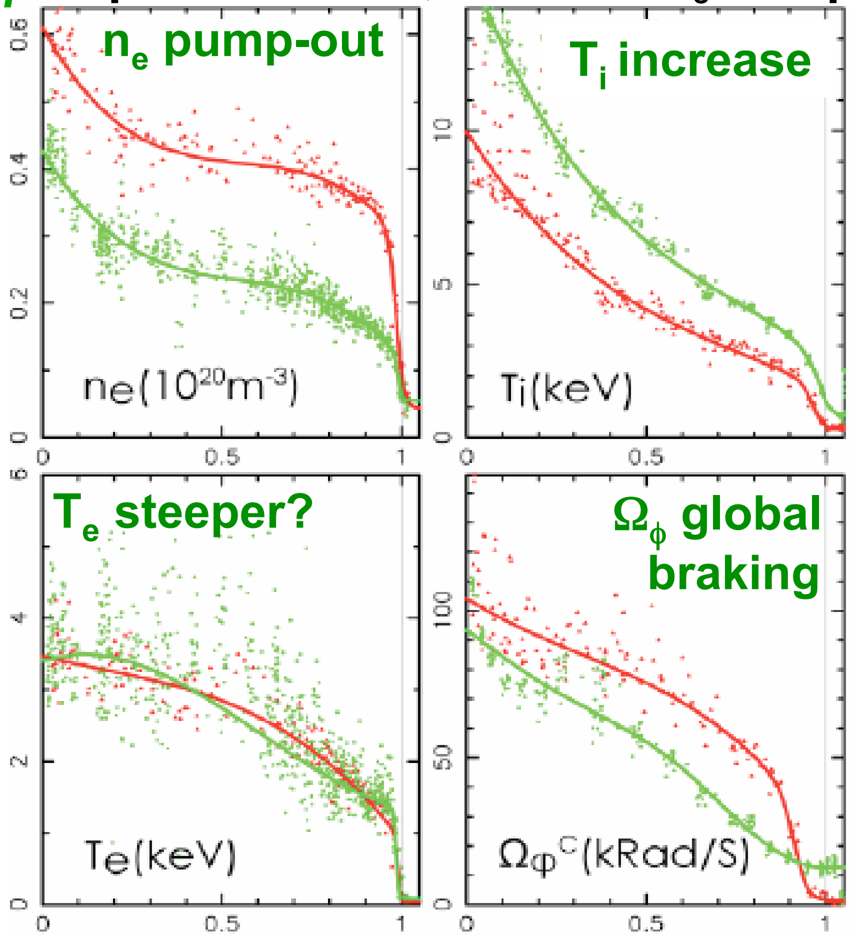
**<< *New ITER design based on collaborative studies***

– *but physics behaviour raises many questions:*

***Is Chirikov right parameter?***

***Effect of screening and resistivity?***

[DIII-D EvansEX/4-1, JET similar Liang EX/4-2]




Much left to do - collaboration is key:

- Comparing different harmonic effects
- Determining action – experimental observation & theory
  - ***Ergodisation, transport, location/harmonics needed***
  - ***Error field interaction & screening effects** (see shortly…)*

# 5. RWMs and high β

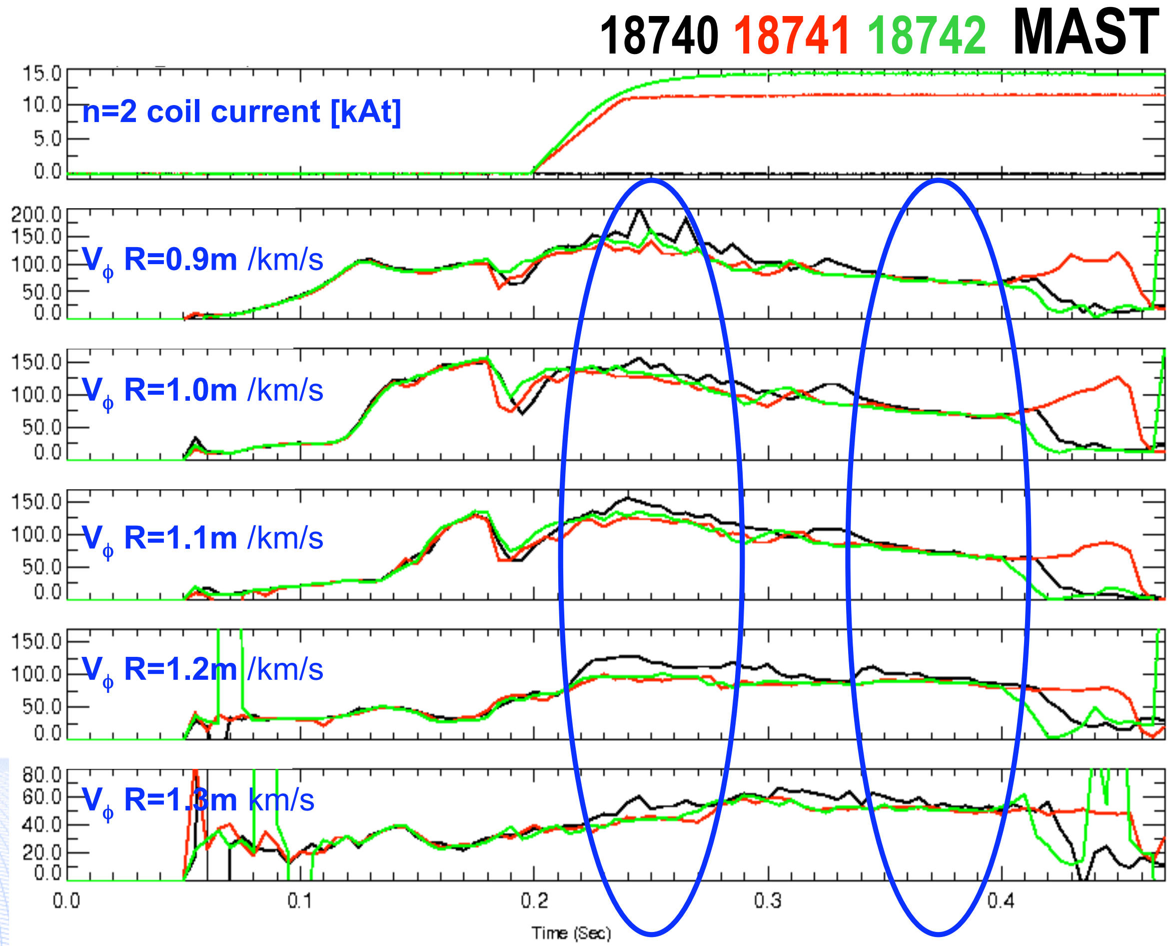
EU focus on:

- **Understanding NTV braking (for ELMs also)**
- Predicting RWM feedback requirements:
  - Dissipation physics and feedback optimisation
- Tearing mode limits to high beta
  - Identify and understand interaction

# Key questions on magnetic braking

Experimentally we see diverse signatures:

- MAST n=2 fields show no significant braking →

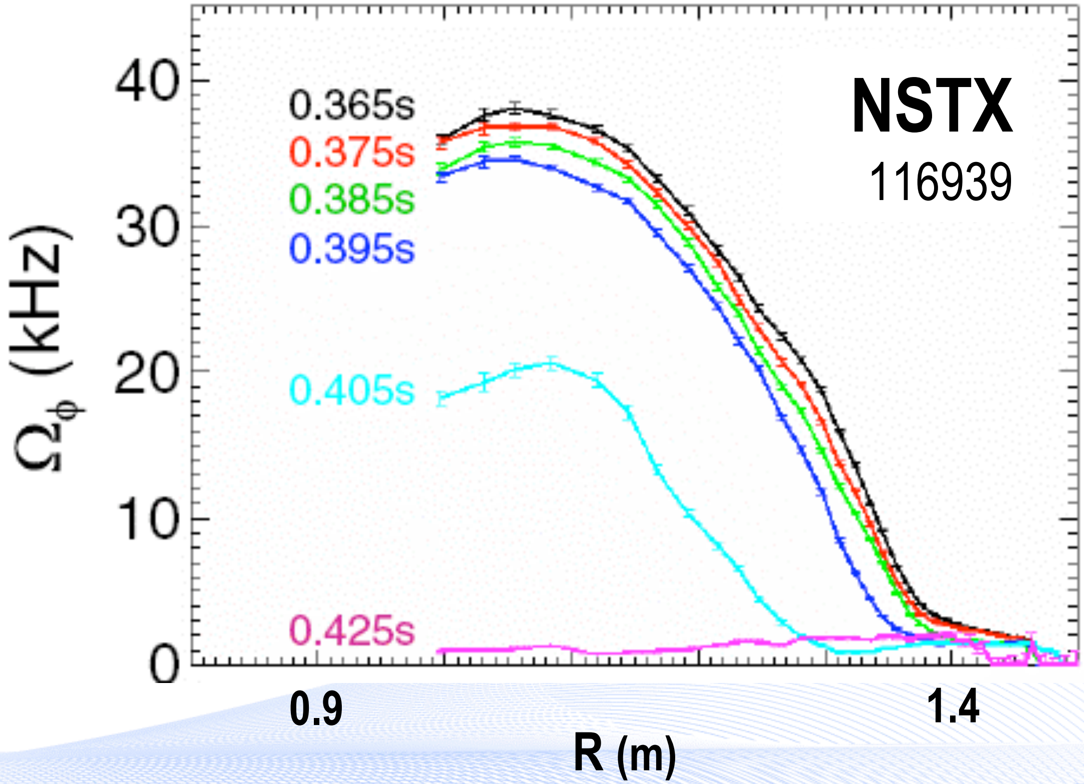



[D. Howell, EFW 2007]

# Key questions on magnetic braking

Experimentally we see diverse signatures:

- MAST n=2 fields show no significant braking
- **NSTX dominant n=1 sees clear NTV braking →**
  - Similar differences between CMOD & JET n=2




[Zhu & Sabbagh, PRL 96 225001]

# Key questions on magnetic braking

Experimentally we see diverse signatures:

- MAST n=2 fields show no significant braking
- NSTX dominant n=1 sees clear NTV braking
  - Similar differences between CMOD & JET n=2

Theoretically, there are several element to consider:

- Resonant interactions of error field
- Coupling through higher order surfaces
- Non-resonant interactions / NTV

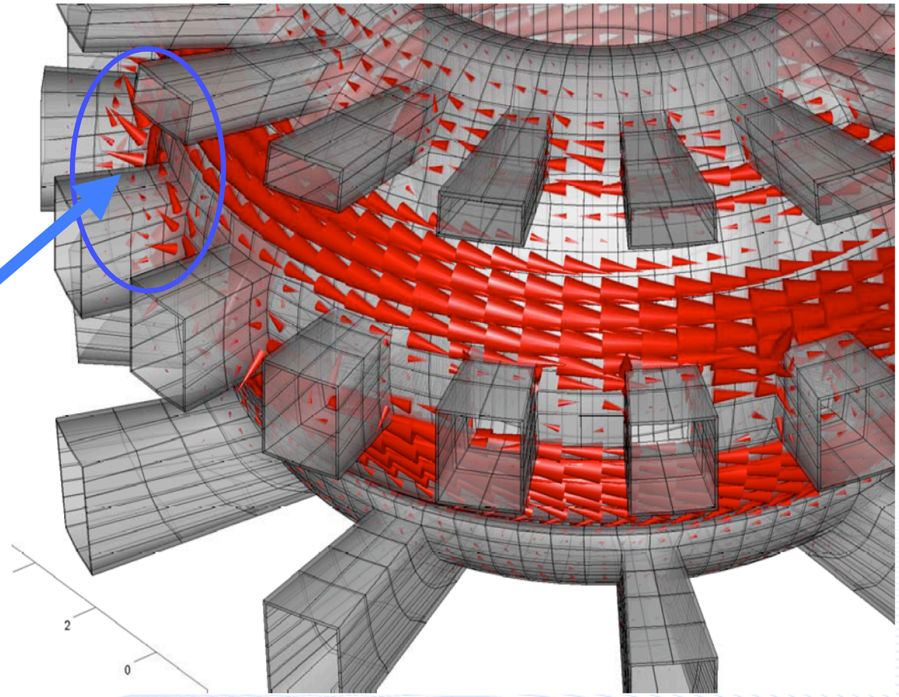
**Collaboration can help deconvolve physics:**

- Reconcile different harmonic effects
- Which harmonics matter & means of optimal correction
- Resolve  unify physics models of interaction
- Park and NTV 'modules' for various codes used by field

# *RWM key physics issues*

- Already very healthy collaboration:
  - Pushing & comparing experiments
  - Testing with common codes
  - Identifying key physics

- An EU focus is to predict ITER requirements
  - 3D wall important
  - Feedback by ELM coils

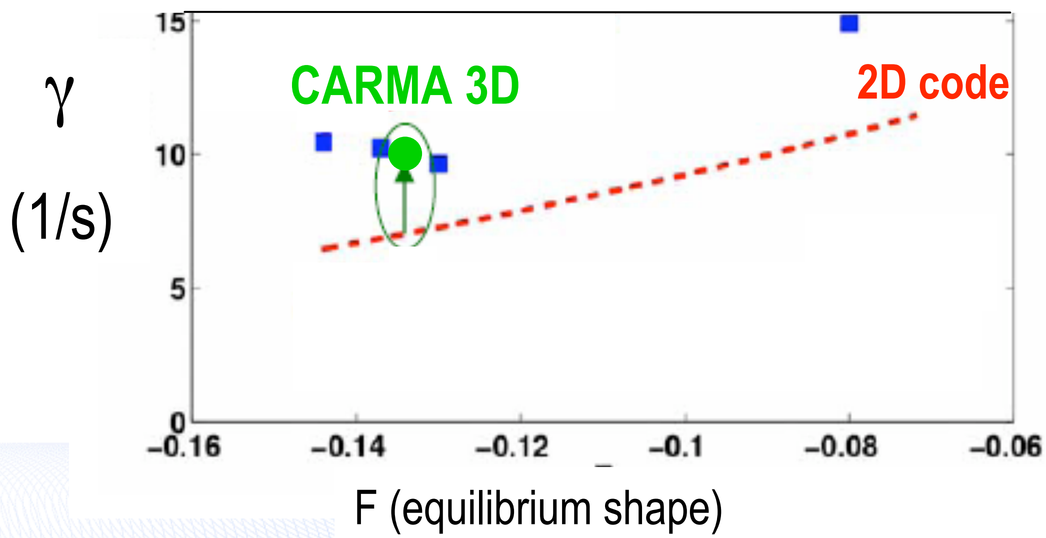



[Liu, APS 2008]

- ***Ongoing close work important to resolve physics models (eg dissipation) and optimise feedback for ITER***

# RFPs good way to get at RWM issues

- Study complex gains and advanced/multimode control
- RFX-mod data (n=5 RWM) used to validate the code, which has been adapted to RFX-mod conditions (including its 3D effects)




| | ETAW | MARSF | CarMa | Exp. |
|---|---|---|---|---|
| $n=4$ | 5.27 | 5.07 | 7.30<br>7.48 | ≈ 6 |
| $n=5$ | 8.63 | 8.55 | 12.8<br>13.1 | ≈ 12 |
| $n=6$ | 14.5 | 14.4 | 22.6<br>23.4 | ≈ 22 |

***CARMA** (MARSF + CARIDDI) is a MHD ideal code coupled with an arbitrary 3D magnetic boundary*

# Conclusions

*The good cooperation between EU and US can be further strengthened:*

- Many areas where it is useful to extend our results comparisons, test codes, extend datasets, resolve and develop physics models
  - More work on disruptions, particular to understand VDE, runaway mitigation and develop disruption response
  - Understanding linear AE stability and holistic picture of fast ion effects
  - New aspects in sawtooth control and NTM physics
  - ELMs – physics governing size and mitigation
  - NTV & magnetic braking major new area to reconcile observations and develop joint models
- EU and US capabilities highly complementary – both strong & cover similar areas – somewhat reinforcing, but with diversity in capability
  - ***We should take advantage of this, using new structure to initiate personal contacts and pick up useful actions***

# Contacts

EU MHD under our five groups:

- **Disruptions:** Valeria Riccardo (UK), Gabriella Pautasso (IPP)
- **Fast Particle:** Simon Pinches (UK), Phillip Lauber (IPP)
- **Tearing:** Patrick Maget (CEA), Valentin Igochine (IPP)
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- Outputs:
  - We should try to pick out **useful joint studies** on above themes
  - Flag areas to pursue with me or above experts, and we will set up relevant contacts

EFDA MHD
EUROPEAN FUSION DEVELOPMENT AGREEMENT

- **Reserve / unused**

# EU priorities – five ‘pillars’

- Development of plasma scenarios for ITER and DEMO
  - MHD!
- Plasma wall interaction and plasma facing materials
- Theory & integrated modelling
  - MHD!
- Emerging Fusion Technologies and Plasma Engineering Techniques
- Fusion as a future energy source

# Disruption summary

- 1. Joint project with US on VDE and halo -
  Where are we on this? Have we started contacts on this. Can you make me a slide setting motivation and making a proposal (good to have a picture/figure to explain in this also)? Do you want me to approach anyone in particular (Steve Jardin?)

  2. Physics based disruption predictor - here I can adapt something from PdV's slides. This is a good one to encourage sharing/complementary testing of good ideas - you agree?

  3. Massive gas mitigation - can we have a slide on MHD goals here? Should we look at what EU and US can do - any points on this?

  4. Impurity diagnostic - here we look for complementarity with US - so ask whether they plan anything? Should we have a slide on this? (do we know what we envisage here now in sufficient detail to make a slide?)

  5. VDE simulation - could outline our plans more generally here (linked to item 1) - mention DINA work, discuss other tools and whether this. This merges into item 1 I think, but is extra slide needed? (or generalise slide under 1). Perhaps thing to do here is have a single slide and motivate a discussion on best tools, ways forward and complementarity...? (can you offer a slide setting up the problem with a nice figure, as requested in item 1?)

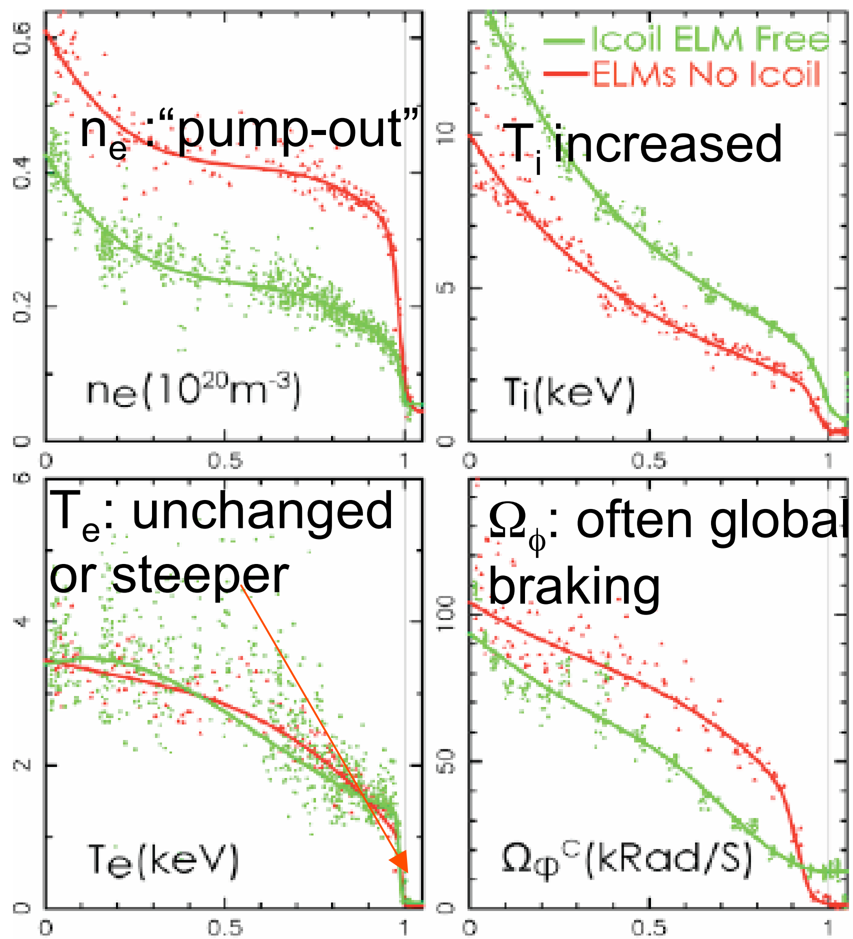
  6. Should we have a further slide on discussion of longer term code capability. Can you draft this and make a briefing? (or could leave this issue in as part of above item 1/5 discussion).

  7. Runaways - yes CMOD have been pushing this (GP saw talk at ITPA) - what collab experiments should we do with them / which bits do EU bring to table (large tokamak avalanche regime on JET... Also AUG...?) Example slide here would be helpful. Perhaps this merges with item 3?

  (8. Disruption database is implicit collaboration under ITPA - no slides needed...? or do you want me to push something?)

# Motivation: Understand plasma response to RMPs

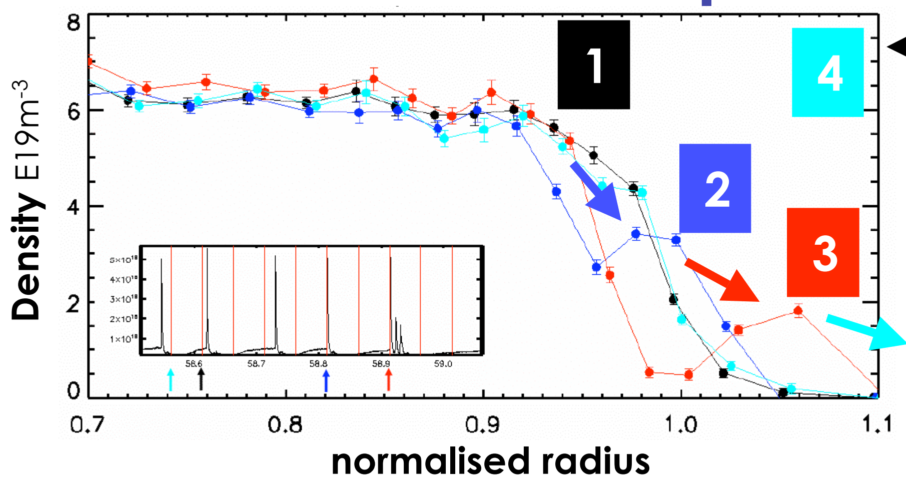
w/o RMPs, ELMy
with RMPs, no ELMs




DIII-D Osborn EPS2005, EvansEX/4-1, similar on JET(Liang EX/4-2)

1) Why ELMs are suppressed?
At present we think: gradP <~ Pcrit,ELM?
2) Is vacuum criterion (ergodic zone for r>~0.9 ) enough for ELM suppression?
Yes: DIII-D, ~JET, not on NSTX,MAST?
3) Resonant window in q95?
Narrow on DIII-D, but it should work for q95=3-5 in ITER!
4) Mechanism for density "pump-out"?
Can MHD ExB (+ || ?) explain?
Turbulence with RMPs?
5) Why is Te flattening in ergodic region not seen in experiment?
Screening RMPs by rotation?
Flux limit in c||?
6) Mechanism for plasma braking/acceleration?
Neoclassical Toroidal Viscosity? Or +….?
……….. etc

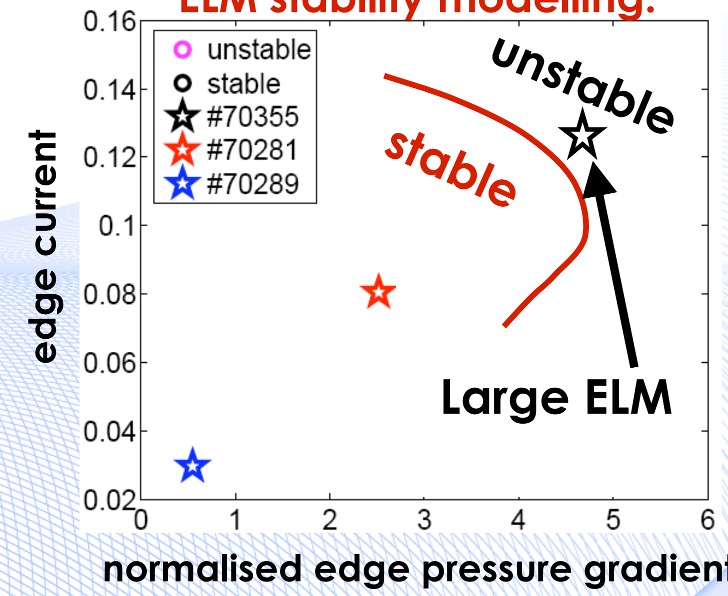
# Archive reference on ELMs require precise measurement of profiles and mode structure




- JET measurement of the composition of filaments ejected by the ELM
  - *Key element in extrapolating ELM physics and heat loads*

- High resolution also enables accurate MHD modelling of ELM
  - Large ELM (☆) occurs in predicted unstable region
  - Confirms "peeling-ballooning" model of the ELM for ***ITER prediction***

ELM stability modelling:



- Old slides from template presentation… (on diagnostics)

# Diagnostics for ELM physics & control

- For stability analysis
  - Accurate edge profiles for $n_e$, $T_e$, $T_i$ and rotation, TS, CX
  - **Edge current measurements**, DIII-D already operates Li-beam [Thomas PPCF 2006] ***- this is key issue for good physics resolution***
- For ELM dynamics studies
  - Fast cameras
  - Fast magnetics, maybe possible to measure even the growth rate of the linear phase – get at mode magnetic structure and ergodisation response
  - Burst TS for profiles inside the filament & other high res profiles (rotation)
  - Reciprocating probe measurements of the filament current and heat fluxes
- For studies of ELM effects on PFCs
  - IR camera for measuring the power flux on the target & wall
    - (scaling – more devices…)

# Diagnostic issues on NTMs physics and control

- Resolving physics questions
  - Threshold physics and seeding mechanisms extrapolation towards ITER
  - Impacts onset criteria and mode stabilisation requirements

    → *high resolution profiles in ne Te rotation*

- Guiding mode control systems
  - Location of islands and resonant surfaces
    - ***Prefer pre-emptive CD - is MSE good enough in ITER?***
  - Size of islands - *magnetics need to be augmented by other diagnostics*
  - Location of ECCD deposition - *precise placement is key*
  - Demonstrations of mode control using ITER like sensors and actuators - *want reliable system on day 2(!)*

# Diagnostic issues for sawteeth physics and control – cnt.

- Fast profiles to understand ***non-linear*** sawtooth evolution
  - & impact on fast ion distributions
  - Improved imaging (SXR tomography)
  - Needs to be on facilities where ITER-like 'ideal' sawteeth occur
- Fast ion populations - vital to sawtooth stability
  - $\gamma$–ray spectroscopy, CTF, others…
- Fine-scale charge exchange
  - Flow shear plays a key role in sawtooth stability
- High-res MSE to resolve $q$=1 radius and core shear

# Diagnostic issues on FP physics

- **Detecting FP driven modes** in ITER
  - High n TAE antenna needed – *is dedicated ITEr antenna needed? (ELM coils?)*
  - Different components of magnetic field (normal, parallel, toroidal)
  - Magnetics challenging for ITER – & will need internal diagnostics anyway– interferometry/reflectometry/ECE *in* ***Alfvén frequency range***
- **Identifying losses** – important for physics now and ITER
  - Further technology to be developed and implement?
    - *e.g. fast ion D-alpha detectors, more IR coverage*
- **Understand FP drives** for influence on modes
  - Fast particle distribution detectors to understand drives:
    - 2D neutron cameras, $\gamma$–tomography, NPA, CTF, FIDA (especially last 2: more needed)

***These aspects need careful consideration of what to apply where – need to consider complementary devices with relevant FP populations & MHD***

# 5. Diagnostic issues for RWM physics

- Physics of rotational stabilization at low rotation
  - Fast ion population for kinetic damping
  - Fine scale rotation measurements to resolve kinetic damping
- Coupling to magnetic islands at low rotation
  - Detailed imaging of MHD instabilities
- Non-linear RWM destabilization by transient events and static error fields
- Implication for feedback control
  - Magnetic sensors

# Summarising slide – Urgent MHD diagnostic needs

- Edge current diagnostic for ELMs
- Improved q profile diagnosis in general – especially for core MHD (sawteeth, AEs)
- Fast profile diagnostic and reconstruction, particularly during disruption (ne, Te)
- Continued push of disruption consequence diagnostics – halos, runaway, full heat accounting
- Fast profile diagnostics for core high resolution core MHD & ELMs (ne Te rotation)
  - **Improved CER diagnosis in particular desired**
- ITER TAE antenna need? / specification / how to include / use of ELM coils?
- Fast particle distributions in core – velocity distributions vs space (CTF, FIDA,…)
- Push towards use of non-magnetic diagnostics for many 'usually-magnetic' problems

IMPROVED UTILISATION:

- Event triggering for many diagnostic systems very important to capture key data
- Integration into control approaches also very important to learn techniques for ITER

- *More discussion with diagnostic experts probably needed to work out which diagnostics required to meet these needs, specification, and which machines (plasma regimes) to apply them.*

# Additional points from discussion… (1)

- "MHD seems in good shape for diagnostics, why more needed?"
  - We understand what modes are, and where they are; the manifestation (i.e. non linear behaviour) requires much more detailed measurements of mode structure; many fundamental (plasma stopping) issues still not at all predictable or suitable control not developed
    - eg ELMs, disruptions, NTM onset, RWM behaviour, & BP physics remains a key concern (losses)
- Most urgent issues seem to be **disruptions** and **ELMs**
  - Agree, and disruptions is a "non-sexy" topic where more focus is needed.
- What are key diagnostic themes / most important aspect to push
  - *(more iteration with MHD TG community to specify properly and agree, but 2 key areas…)*
  - Imaging – to see & quantify structure of instabilities in plasma
    - Needs for fast high spatial and time resolution measurements of profiles (ne, Te, rotation)
    - q profile a key aspect to improve measurement of if possible
  - Edge – very detailed diagnostic to see structure and evolution
    - Vital input for MHD models, understanding non-linear process and mitigation techniques.
    - Most important is improved q profile diagnosis in the edge

# Additional points from discussion… (2)

- Control is a key theme
  - Yes – devices need to much more routinely integrated diagnostics real time into control systems and use for MHD avoidance
    - ***need to develop the 'habit' and expertise for doing this***
- FP physics seems well provided for…?
  - Well, many new and useful tools at JET, but much further needed to really quantify role of fast particles in influencing things like
    - Fast particle distributions with things like CTF and FIDA a key area / gap for physics and diagnostic development
- MSE has limits in its capabilities – MHD itself can often be best diagnostic
  - True, but profile information vital in understanding issues like sawteeth, ELM and fast particle instabilities – measures of magnetic shear are very helpful
  - A holistic (Bayesian?) approach is required to integrate diagnostics

# Issues to consider further…

- **TAE antenna for ITER – is dedicated one needed? Are ELM coils enough?**
  - Solicit input from TAE community
  - But not that ITER is the research machine for DEMO, and AEs are one of the key new areas of physics that manifest progressively worse from current→ITER→DEMO

- **What have we missed?**
  - And is EFDA's limit of 2-3 key issue too restrictive (next slide…)?

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# Principle issues from later EFDA TGL discussion – even more focussed

- Some key priorities:
  - Imaging, particularly for ELM and disruptions (but also for non-linear MHD)
    - **SXR tomography, calibrated and augmented by other diagnostics**
      - **Need to identify specific hardware proposals for next 2 years – where needed and beneficial? → GOAL FOR MHD TG MEETING TO SPECIFY**
    - **2D ECE imaging**
      - **Being taken from TEXTOR to AUG**
  - Edge current diagnostics – a challenging field; proposals will be invited. Possibilities:
      - **Between and during ELMs**
      - **Seems a key strategic need for sustained long term action**
      - **Has ramifications outside MHD as well - pedestal**
    - **Polarimetry**
    - **Heavy ion beams and their deflection**
    - **Edge probes – particularly in smaller devices**
  - Control
    - **Identify projects to consider choices of sensors: Br vs pol; non magnetic sensors**
    - **A THEME: Integrate diagnostics into real time control systems for routine MHD avoidance – of disruptions, ideal limits (probing, calculation), etc.**

***Seems to narrow – we should seek more?***