Ideas for MHD Contributions to ITPA MHD Studies

Stefan Gerhardt

- Disruptions
  - Priority in this presentation determined by priority in the draft high-priority ITPA research topics.
- NTMs
- DEFC
- Some ideas about the "low-hanging" fruit, since Steve is supposed to present just a few ideas on Monday

If something is a problem for ITER, then it is probably a problem for a CTF or burning ST as well.

Disruption Physics and Mitigation

Develop ITER applicable disruption mitigation techniques. For massive gas injection, understand optimal gas mixtures, their assimilation properties and the influence of MHD on impurity penetration to the core. Study the ability to suppress secondary runaways. Develop reliable disruption prediction methods and understand diagnostic requirements.	• **There are several issues for which we would prefer to have the solution now (improved data and analysis within the next 12 months for Licensing):**
	  • **a more complete validated modelling capability for VDEs, including halo currents, to strengthen the basis for predicting vertical and horizontal forces**
	  • **a validated modelling capability for runaway generation and loss to allow an improved assessment of first wall energy deposition**
	• **An improved assessment of SOL width and local power deposition during disruptions/ VDEs, including limiter plasmas**
	• Three key questions:
	  • is Rosenbluth density required for runaway suppression?
	  • if so, is "killer pellet" a viable alternative to MGI (higher assimilation)?
	  • are other alternatives, eg stochastic magnetic fields, effective and viable?
	• Need to understand:
	  • quantitative extrapolation of technique to ITER
	  • reliability of routine use
	  • Implications for use in ITER - technology R&D? impact on operations?
	  • first wall heat loads produced
	  • Influence on runaway electron generation/ suppression
	• experimental demonstration that a technique or combination of techniques allows reliable mitigation of disruption effects
	• "mitigation" implies:
	  • heat loads, runaway electrons: reduction by more than 1 order of magnitude
	  • forces: reduction by factor of 2 to 3
	• key effects are:
	  • local heat loads
	  • vertical/ horizontal forces
	  • runaway electron currents (energies ?)
	• significant modelling development to provide basis for ITER extrapolation (specification of DMS in 2009:Procurement in 2012)

Essentially Same Text in Boundary Section-> Joint XPs are appropriate
Agreed that this is "Low Hanging Fruit"

MS XP-9XX

VDE Thermal Quench Characteristics

S.P. Gerhardt, R. Maingi (T. Grey), K. Tritz,…many others

Ambitious Goals

1. Quantify the thermal quench time-scale, in terms of both plasma energy loss and divertor heat loading.
2. Determine the spatial distribution of themal loading during a disruption.
3. Determine radiation/conduction power balance during VDEs.

Part 1 Requires Devoted Machine Time, Part 2 is Piggyback.

Part 1: Deliberate VDEs (29 shots including contingency)

Step 1: Reference Shot: XXXXXX, high-κ LSN, 4MW, gap-control algorithm, I_P=1000kA, B_T=0.45 kG, No SPAs, VTOP with 10μm filters (3 shots)

Step 2: At t=XXX, freeze PF3 voltage, then apply pushing voltage to force VDE, make necessary diagnostic adjustments. (4 shots)

Step 3: Repeat Step 2 with VTOP filters at 5μm, bolometry (6 shots)

Step 4: Repeat at 1.1MA, two VTOP filter settings (6 shots)

Step 5: Repeat at 0.7kA, two VTOP filter settings (6 shots)

Step 6: Add enormous amounts of LFS gas $\rightarrow$density limit disruption (4 shots)

Part 2: Pressure Limit Disruptions

Using the optimized diagnostic setup developed in part 1, repeat measurements during high-β XPs where pressure-limit disruption limits are likely.

Many Important Diagnostics Are New or Need Refurbishment

- Fast IR Camera Viewing Lower Divertor
  - *Essential*
  - *Timescale and spatial distribution of divertor heat pulse during thermal quench*
- USXR chords from VTOP array
  - *Essential*
  - *Timescale for thermal energy loss from core plasma.*
  - *Use of different filters allows $T_e(t)$ measurement?*
- Divertor Bolometry
  - *Nice to have*
  - *Radiated power from lower divertor, the region of the disruption*
- Fast Diamagnetism
  - *Nice to have*
  - *Timescale of thermal energy loss*

However, Runaways are the Outstanding Disruption Issue for ITER

- Three mechanisms for runaway generation.
  - Dreicer Mechanism.
  - Avalanche mechanism, weak in present tokamaks but expected to be VERY strong in ITER.
  - “Hot Tail” (proves seed mechanism in “Killer Pellet”).
- Funny trends at conventional aspect ratio (ignoring MGI cases).
  - Runaways almost never observed in divertor tokamaks (VDE eliminates runaways?). Killer pellets are the exception.
  - Runaways not observed for B_T<2T
- NSTX has never observed disruption runaways (if you have seen them, let me know).

If we are serious here, we should try to generate some runaways.

1: Inject impurity pellets, for instance up to 8 simultaneously with LPI
2mm each, up to ~100 m/s (~3mm, 500 m/s in DIII-D Ar, Ne KP)
Pick correct material.
Rapid cooling might lead to “Hot Tail” runaway generation.

2: *Use n=1,2,3 fields to suppress runaways via stochastization.*

3: Use CTs to suppress runaways

Strong Focus on Mitigation in ITPA Requests

- Mitigation means forces reduced by 2-3, runaways and heat load reduced by order of magnitude.
- Rapid response of mitigation system eases requirements on disruption detection algorithms.
- Killer Pellets are Mentioned
  - Tend to generate runaways.
- MGI is prominent in ITER plans:
  - Assumed that only a fraction (20%) of the injected gas is used by the plasma.
  - This assumption is unverified…the energetic ITER edge renders penetration fractions predictions unclear.
  - MGI brings vessel to 1 Torr, required cryo-pump regeneration, at least three-four hours to get going again.
- Stochastic fields for runaway suppression is another important mitigation technique.
- Jon asked Roger to look into CT injection as a fast shutdown scheme.

Roger's (and My) Thoughts on Mitigation by CT Injection (work in progress)

Advantages

- MGI gas travels at the sound speed, the spheromak would travel much faster.
  - Slowerst component is likely the injector gas valves (~200 μs), compared to MGI times of 5-15 msec.
  - Ease the requirement on the disruption prediction system.
- Depth of penetration can be adjusted via acceleration voltage.
  - Tailor penetration to the edge, near q=2, core.
- Operation of the injector in Marshall gun mode
  - Causes a long trailing plasma with significant neutrals (>10^2 more than CT).
  - These neutrals travel faster than in MGI, and penetrate more deeply
- Could be used in combination with MGI.

Questions?

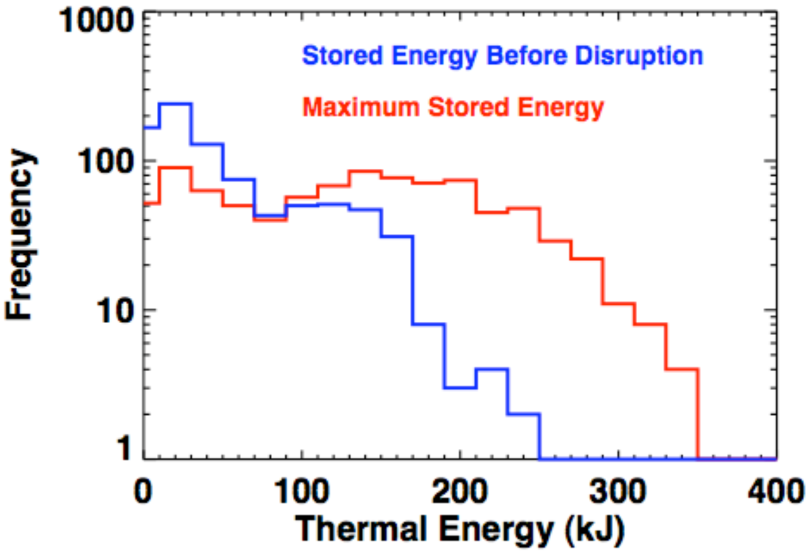
- Could this produce the "Hot Tail" runaway distribution that the avalanche process accelerates to destructive levels?
  - Might increase the criticality of achieving collisional damping of the tail.
- As a consequence, may be viewed as complementing other mitigation techniques (MGI, stochastic fields).

Potential NSTX Goal (From Roger)

- The ability of the CT to vary the gas composition and to inject the required gas on a faster time scale would allow NSTX to begin to quantify and understand in greater detail the actual minimum gas injection requirements for ITER, the required penetration depth, the need for some core impurity injection in combination with bulk outer gas injection and finally importance of spreading the injected gas over a larger minor cross-section on a fast time scale.

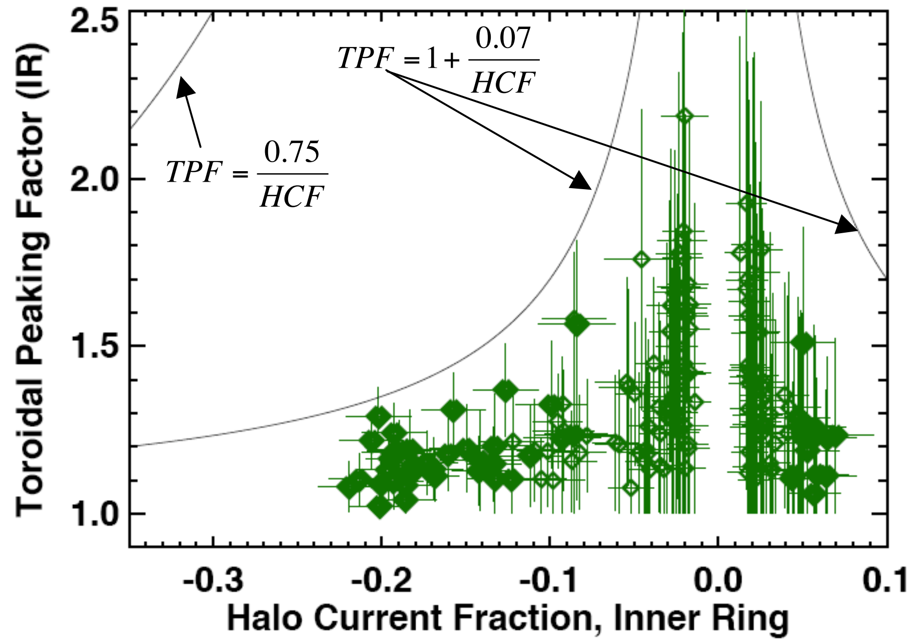
Other Disruption Things…

> Continue development of the disruption DB to include pre-disruptive energy loss and halo current data.



ITPA has not released a formal specification for the formal of this data, so I can't contribute anything yet.

Inner Ring, TPF vs. HCF



- New in FY09, Instrumented Tiles, Halo Currents into LLD.
- ITER requested HC modeling. I don't have time to do it.
- Richard Buttery informally proposed an increased modeling effort.
- ***This should be pursued in parallel with the improved diagnostic coverage.***

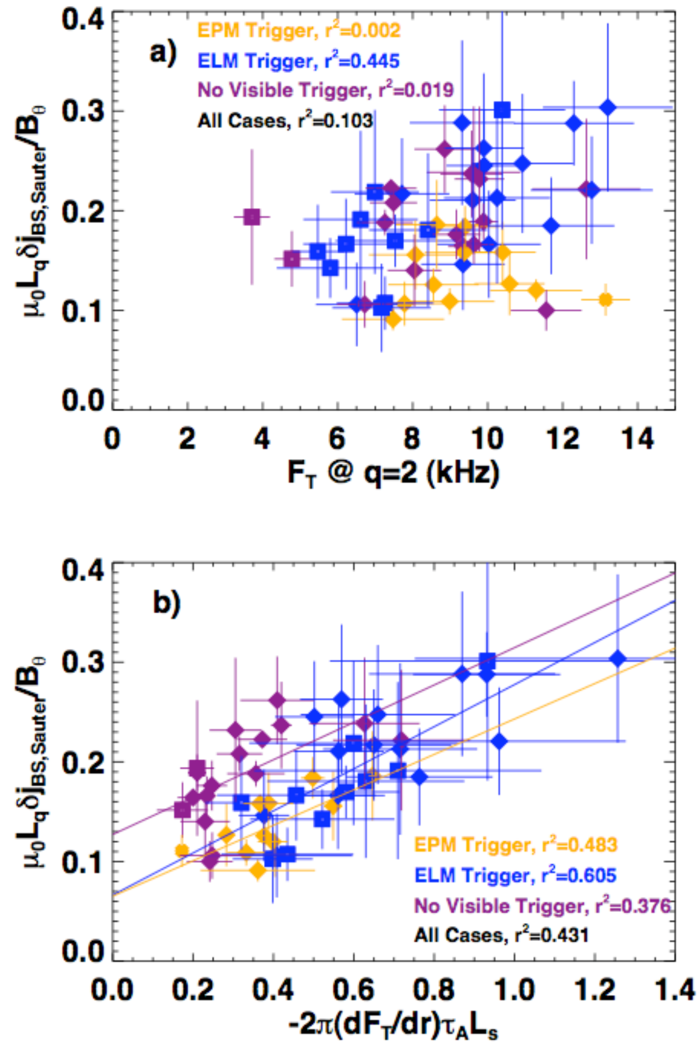
Mitigation Only Works of Disruptions Can Be Predicted (MDC-1, Mitigation by Massive Gas Jets, kinda)

- Faster mitigation schemes ease requirements on detection, faster detection eases the requirement on mitigation.
- Neural-net appears to be the default method for ITER (am I correct here?).
- We may have some simple schemes that would work in NSTX.
  - Rotation decay proceeds all locked 2/1 modes, real-time n=1 detection possible.
  - Deviation of vertical position from Isoflux request indicates trouble.
  - RWM detected by internal sensors, trigger off of n=1 amplitude.
  - Current ramp disruption requires more thought.
  - RFA detection for with-wall proximity…fascinating but non-trivial.
- These are clearly applicable to ST-CTF, not so clear about ITER. Needs more study on my part.
- This is an analysis & data mining task…could start a lower-level effort, though maybe at the expense of something else.

NSTX Has Lots of 2/1 NTM Data…

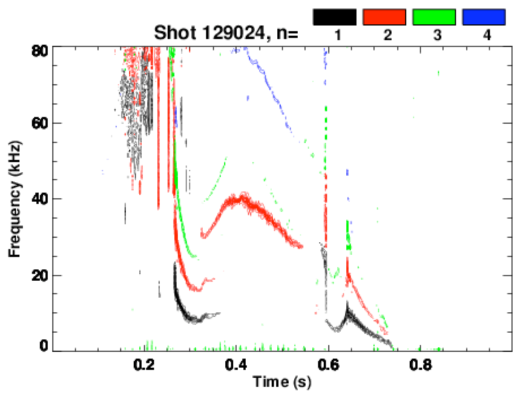
> Study NTMs in Hybrid Scenarios, the effect of plasma rotation, validate ECCD control models against data (including modulation) and specify diagnostics for NTM detection.

- The standard NSTX shot is kinda "Hybrid".
- Very near to publishing a thorough & ITER relevant study of rotation and the 2/1 mode onset (MDC-14).
- No "ITER relevant" control tools.
- Could maybe contribute on diagnostics side…need more info to comment on that.



…but there are more things that could be done.

- 2/1 mode
  - Try (again) for error-field effects (See Richard B.'s XP proposal for detailed rational, MDC-3).
    - Previously frustrated with unreliable mode-onset.
    - New understanding of triggers could help (try to get the shot to ELM?) Run before lithiumization.
  - Try (again) re-stabilization, but at lower κ & δ (MDC-4).
    - Important measure of the aspect-ratio dependence of small island effects ($w_{marg} \sim 2\varepsilon^{1/2}\rho_{\theta,i}$).
    - This should decrease the L->H threshold, and thus (hopefully) the H-> threshold. Are there other shaping tricks?
    - Candidate Shot: 129024, κ=1.8 & δ=0.5
- 3/2 mode
  - Difficult terrain, as 3/2 islands are very uncommon.
  - Shot development required, maybe with sawteeth?
  - Candidate Shot: 129898, I_p=600kA, B_T=0.3T (no MSE).



Restabilization of the 2/1 is probably simplest to try, but none of these are "easy".

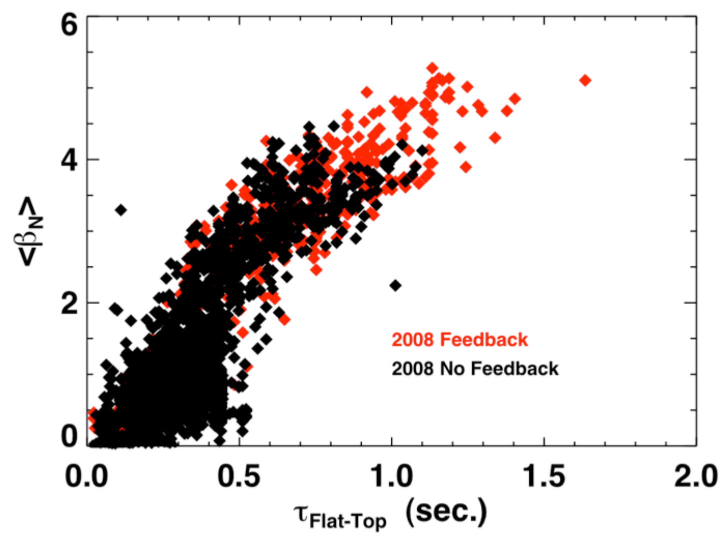
We have a big need in theory/modeling support.

- Modes are observed to be ELM or EPM triggered. What is the nature of the coupling? (ELMs appear to trigger 2/1 modes in JET and DIII-D as well.)
- Some modes have no trigger…are they Δ' unstable?
- Or, in the language of [Brennan, NF 2005], are some modes of mixed onset and others seedless? ITER hopes to avoid NTMs through seed-island control.
- 2/1 modes are always coupled to 1/1 modes. How does this change the stability properties.
- *Since all onset types have a rotation-shear dependence, the dependence is likely in Δ'. However, no published theory (that I know of) can fully explain this.*

An early-stage RWM/DEFC idea…
Relative Role of Fast and Slow Feedback

For RWMs understand mode damping particularly at low rotation. 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.

Quantify effects of non-resonant error fields, specify multi-mode error correction requirements and error field thresholds at high ß.



These are related topics…DEFC algorithm trained by canceling applied error fields at high-β
Relevant to MDC-2

- Slow Feedback=DEFC, Fast Feedback=RWM feedback, both were playing a role in the 2008 success, but what was the balance?
- Use a shot that pukes as 0.5 sec without FB.
- Turn on “optimized” feedback, slowly increase low-pass filter constant (slowly transition to DEFC only).
- Then use NEW highpass filter with short time-constant to include only RWM feedback
- Slowly lengthen time-constant to transition back to optimized state.
- If done in high-rotation state, then CTF/NHTX relevant, if in low-rotation, then ITER relevant…if up to SPG, then do in high-rotation state.

Fun and Easy Things To Do *Some Ideas*

(besides sleeping, watching NASCAR, drinking beer, planting flowers, playing with the baby, drinking beer, reading things that are NOT about plasma physics, listening to Beethoven, vacationing, drinking beer,…)

Short Term (this year)

- Thermal Quench Characteristics (Joint MS/Boundary XP)
- One Last Try at 2/1 Mode Restabilization, (marginal island width for the 2/1 NTM), in an "improved" shape.
- NTM Modeling: effects of rotation, linear stability
- Clearly, continued RWM-FB/DEFC experiments, possibly including (something like) the previous ideas.

Longer Term

- Fully flesh-out the CT injection idea, determine a strategy to implement it, possibly along with MGI.
- Assess disruption prediction techniques…what measurements are most important and how are they to be used.
- Integrated Disruption Modeling
  - VDE motion+Halo Currents+Current Quench
  - Thermal Quench Dynamics
  - Runaway generation
- Control or rotation and current profile, triggers, for 2/1 NTM control.

This list is seen through the glasses of Jon's request.
There are many other important research tasks, not included on this list!