United States
Burning Plasma Organization

U.S. Burning Plasma Organization: MFE Research in Support of Burning Plasmas

Amanda Hubbard, MIT PSFC

Deputy Director, USBPO

Fusion Power Associates
34th Annual Meeting and Symposium
Fusion Energy: Visions of the future.
December 11, 2013, Washington, DC

Strong need for US research in support of burning plasmas!

- **ITER is now under construction, but is much more than a construction project.**
- While much of the design is complete, critical issues remain and decisions are being made now, on the basis of worldwide magnetic fusion research.

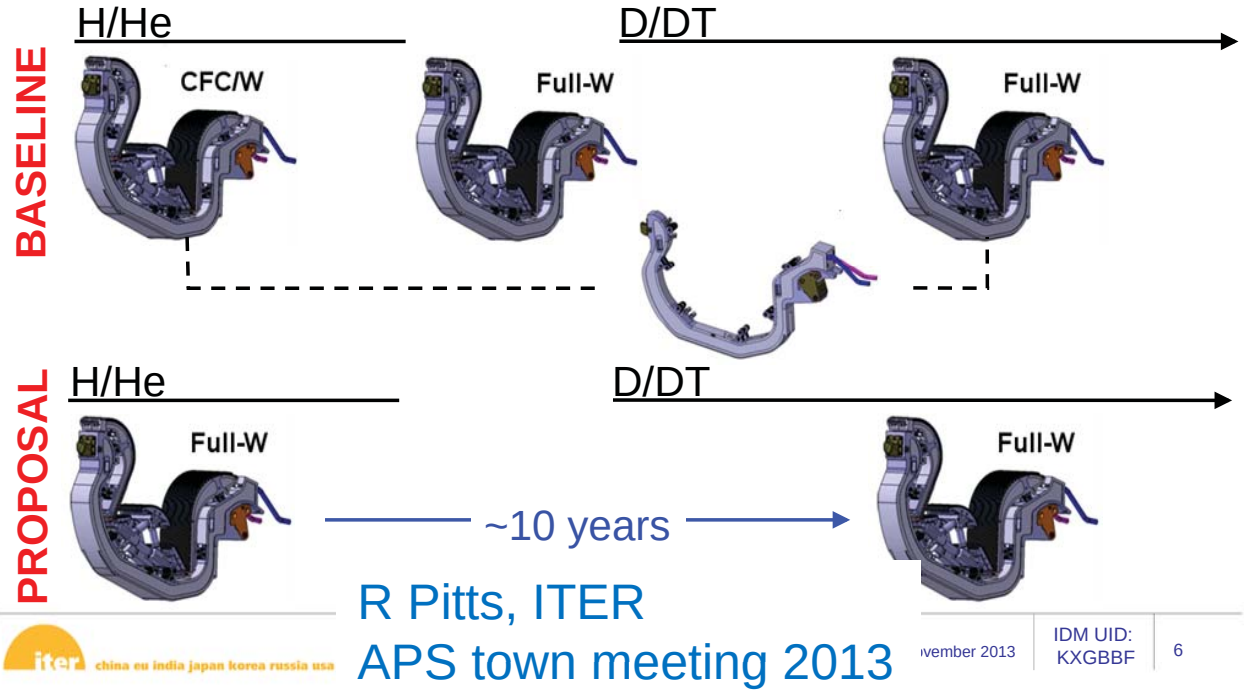
- Current and ongoing research also inform the experimental planning for ITER, both the early operation (eg, high confinement regimes in reduced field, non-nuclear phase) and scenarios to meet ITER's goals (Q=10, and steady state).

- Also need to build teams to exploit ITER physics.
  Ultimately, the parties which get the most out of their investment will be the ones which have the strongest research teams in the period before ITER operates.

Examples: Two big decisions made Nov 2013 by ITER Council

#1 New divertor strategy

- IO proposed in 2011 to eliminate first CFC/W divertor and begin operations with a full-W variant which should survive to the end of the first DT campaign



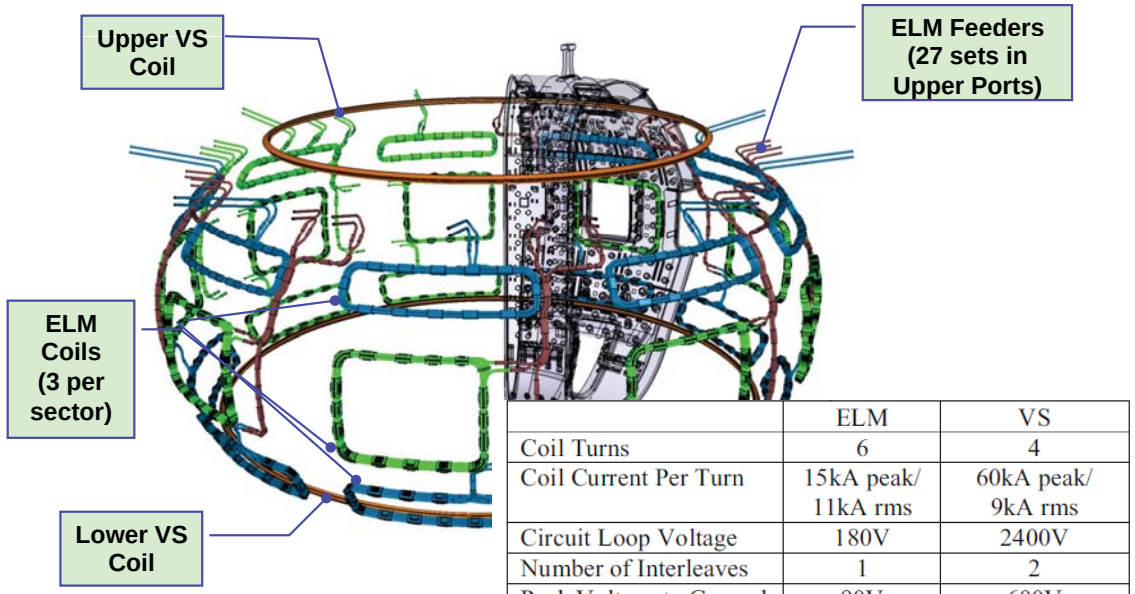
Main issue is that Carbon, used by most tokamaks, will likely retain too much tritium to be licensed in DT phase.

Multi-year study by several ITPA groups, and engineers, informed ITER Science and Technology Advisory Committee (STAC) recommendation.

Bottom line: There will be issues with W divertor. But, ITER will need to address them in any case, not made markedly worse by facing earlier. The change will affect the research plan. Do need ongoing R&D on boundary physics, and operation with metal walls!

#2: Install in-vessel coils to control Edge Localized Modes and vertical movements

Design Overview



	ELM	VS
Coil Turns	6	4
Coil Current Per Turn	15kA peak/ 11kA rms	60kA peak/ 9kA rms
Circuit Loop Voltage	180V	2400V
Number of Interleaves	1	2
Peak Voltage to Ground	90V	600V

27 ELM (Edge Localized Mode)

Provide Resonant Magnetic Pertubations at 5 Hz; Consider RWM in future

2 VS (Vertical Stability)

Stabilize 15 MA plasma up to Z_o = 16.5 cm

Issues are

1) **Edge Localized Modes** cause pulses of heat to divertor, which would erode it – need to stabilize them.
2) **Vertical instability** could lead to very damaging disruptions.

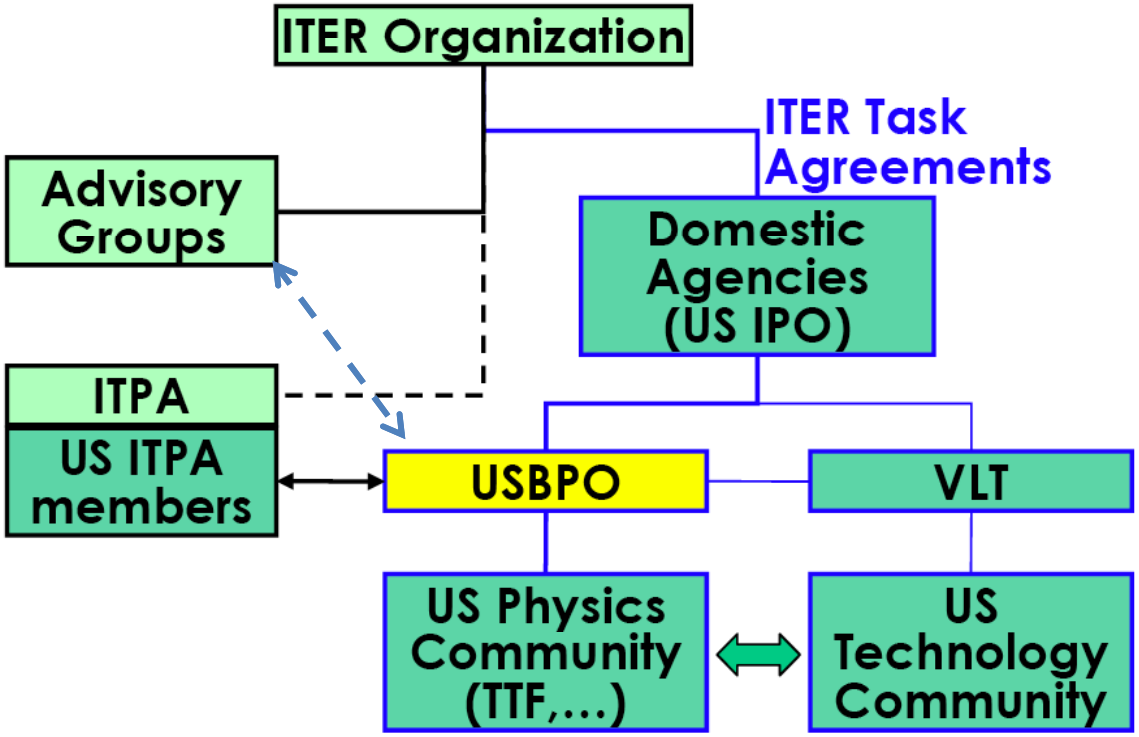
E. Daly, ex-ITER
APS town meeting 2013

ITER IVC Design and Status – APS DPP NOV 2013 Slide 7

- Again, there has been a recent multi-year effort to establish confidence that RMP coils should work, and are robust & redundant enough – very challenging engineering. US has been a leader, especially in RMP ELM stabilization, first demonstrated on DIII-D. But, physics issues remain – other devices finding different results.

USBPO role is to support ITER via US MFE program

- **US ITER Project Office**
  - US Domestic Agency for ITER
  - Provides hardware & technical contributions
- **USBPO**
  - Coordinates US burning plasma research, to advance scientific understanding & ensure greatest benefit from ITER
  - USBPO Director, Chuck Greenfield, is also the US ITER Project Office Chief Scientist, and on ITER STAC.



  - He is also on the ITPA Coordinating Committee, which is meeting this week in St. Paul lez Durance.

USBPO Mission and activities

USBPO Mission

Advance the scientific understanding of burning plasmas and ensure the greatest benefit from burning plasma experiments by coordinating relevant U.S. fusion research with broad community participation

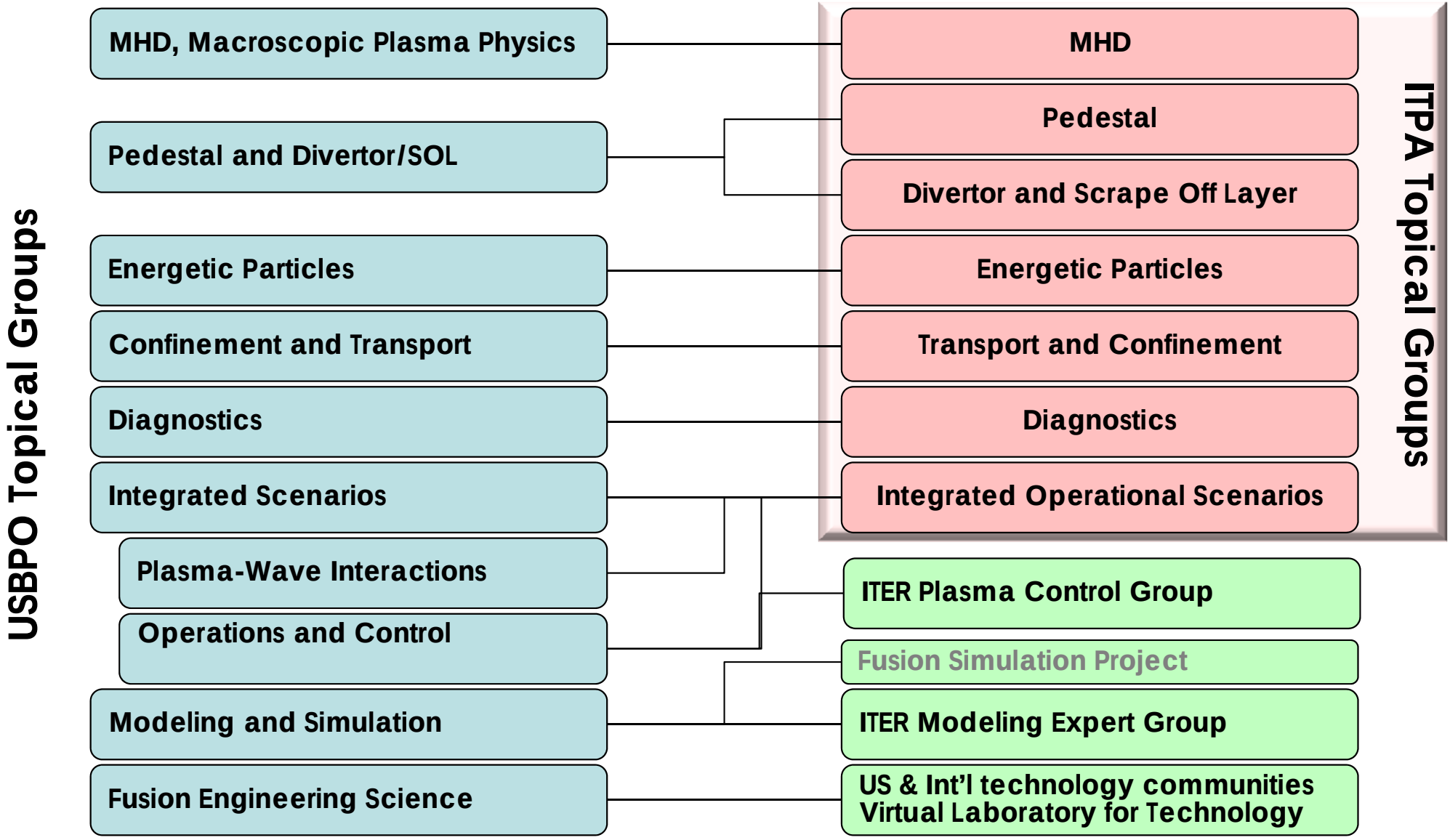
Activities can be divided into three main elements:

1. Communication. Ensuring that a broad community of interested and qualified researchers is well informed about and engaged in solving current burning plasma issues.

2. Coordination. When it is beneficial, coordinate and help prioritize US research on selected issues.
Actual research is done by FES-funded laboratories.

3. Preparation. Prepare for operational phase of ITER, by encouraging broad, open participation and eventually helping form well qualified teams so US will maximize scientific benefit.

Working to strengthen links between USBPO topical groups and ITPA, other groups



Enhanced communication between ITPA and USBPO community

The issue:

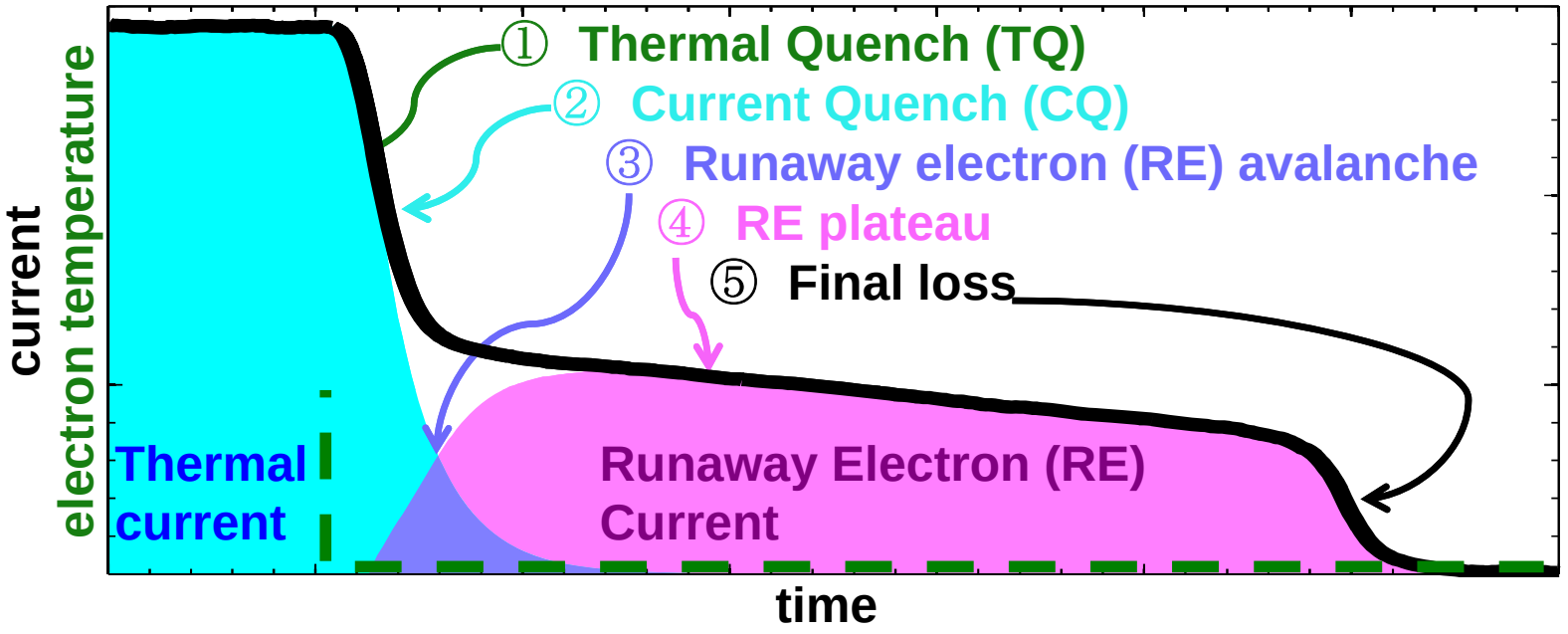
- **ITPA (International Tokamak Physics Activity)** groups have members from all ITER parties, meet twice a year in different countries.
  - Each party limited to 7 members. Most are from large facilities.
  - While US allows other experts to attend, travel costs in practice limit participation. Access to ITER-hosted website is now restricted.
- **USBPO membership** is open to all interested in any topical group.
  - Currently 377 members, from many institutions of all types and sizes.
- Several means being used for regular communication:
  - **E-News.** Monthly newsletter (to 588 subscribers) includes short summaries of upcoming topics in advance of ITPA meetings, and highlights afterwards.
  - **E-Mails to BPO Topical Group lists**. Can provide more detailed information such as ITPA agendas and meeting summaries.
  - **Forum.** Post similar content for future reference, broader access.
  - **Web seminars.** Online presentations to BPO community, with open discussion.

Web seminars are proving most popular and effective

- **Based on participation and community feedback, web seminars are an effective tool.**
  - Made possible by ESnet tools (ReadyTalk, H323) provided by DOE.
- **Reestablished more regular series in 2013,** some on ITPA and others on broader ITER topics. Recent examples:
  - June 12: **Energetic Particle Physics ITPA**, Eric Frederickson (PPPL).
  - July 24: Status of **US ITER Diagnostic Development**, D. Johnson (PPPL).
  - September 25: **Challenges and R&D needs for combined thermal and magnetic energy mitigation in ITER**, John Wesley (GA).
  - Dec 9: **Transport and Confinement ITPA**, George McKee (U. Wisc) and Gary Staebler (GA).
- Participation varies, and cannot be exactly counted, but is large – Typically > 30 Ready Talk connections + ~3 large groups on H323, **60+ participants.**
  - Notably, we always get many participants from small groups, beyond the large fusion labs. Universities report that students are engaged.
- Expect to expand seminar series in 2014 – many topics being suggested.

Example of Coordination: Disruption Task Group

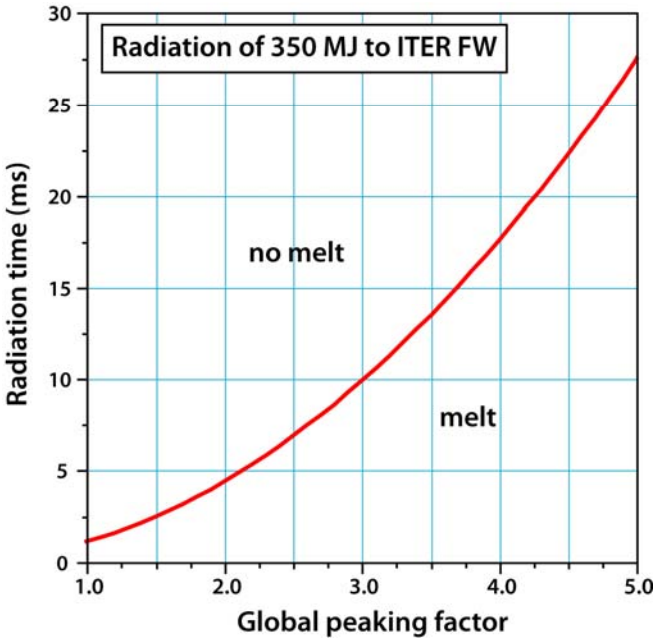
- In many cases, ITPA communication and facility program planning processes provide sufficient coordination– then BPO stays out of the way.
- In some cases a task group is set up to broaden participation, focus attention. A current example is Disruption Mitigation.
- Disruptions (sudden loss of plasma current and energy) have potential for serious damage to a fusion-scale device such as ITER!



C. Greenfield, APS 2013

Example of Coordination: Disruption Task Group

- Disruptions must be avoided where possible, if not, “mitigated”: take action before or during a current quench to reduce forces, spread out heat.
- Disruption Mitigation System is a new US responsibility, not in baseline. Many key decisions needed before design reviews in next 2-4 years.
  - *What type of system (gas, pellets?)*
  - *How many locations needed?*
- While specifying is a shared responsibility for whole ITER/ITPA team, US has a key interest in making the best decisions, soon!

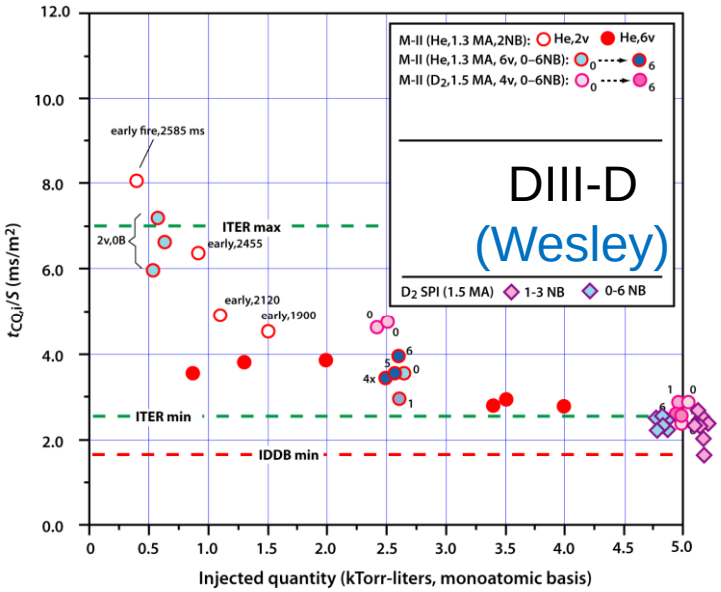


Wesley, BPO seminar

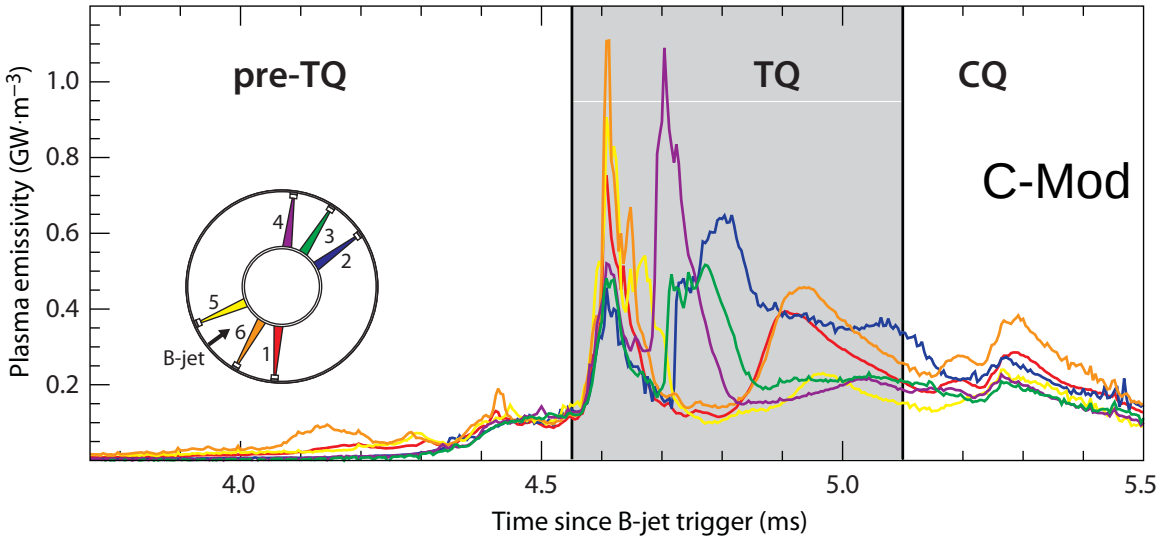
- Task group led by Bob Granetz (MIT), John Wesley (GA), members from across US. Started with 2012 workshop. PPPL held 2013 theory workshop .
- **Feedback from STAC is that disruption mitigation is likely to be a high ITER priority in 2014.**

Progress on quantifying quench time, peaking and asymmetries.

- In 2013, focussed mainly on mitigation of thermal and mechanical loads by massive gas injection.
- Quench time must be not too slow (excessive heat & forces) – or too fast (excessive torque). Studying variations with type, quantity of gas on DIII-D.



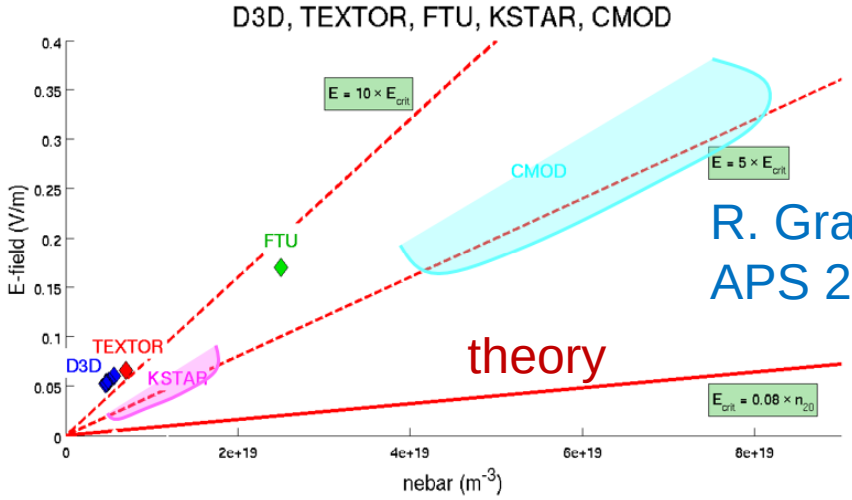
- Experiments have shown poloidal and toroidal peaking, which varies a lot and can be *worse* with multiple jets.
- Recent C-Mod analysis and modeling show this unexpected result is due to MHD instabilities, reduces if mode rotates. *Can this be controlled for ITER?*



G. Olynk, MIT Ph.D. thesis

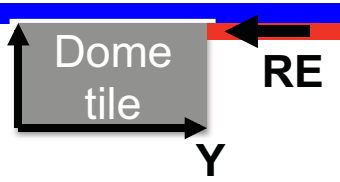
Many critical issues remaining, especially runaway electrons

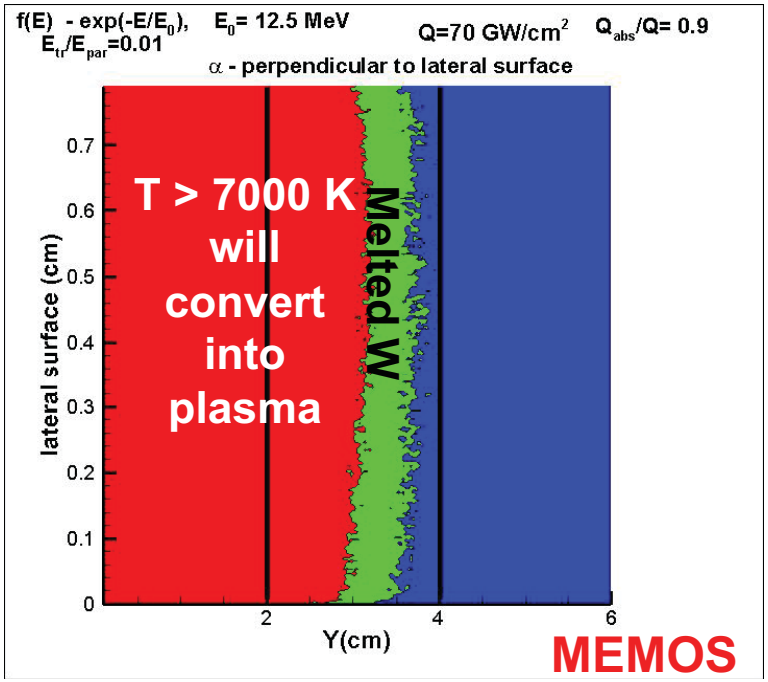
- **Bad news:** Runaway electrons during ITER disruption pose potential for very serious damage – in worst case melting W divertor, or Be first wall.
- **Good news:** ITPA study shows density needed to stop REs is 5-10x lower than theory predicts.



R. Granetz, APS 2013

R. Pitts, ITER APS 2013





- Example: fast RE loss: t_{loss} = 100 μs W_{RE} = 20 MJ, E_{RE} = 12.5 MeV

- **Open issues:** *What is the additional mechanism quenching runaways? How will limit scale to ITER? Can ITER reliably meet this limit, at the same time as other mitigation requirements?* Need **improved theory** as well as more experiments!

Preparation: Task Group on 'Modes of Participation on ITER'

- As ITER project rightly focusses on construction, we also need to consider how the experiment is going to operate. Surprisingly little has been decided about the operating phase.
- While this may seem premature, key decisions are being made, NOW, about CODAC which will affect what is feasible later.
  Eg, How are experiments proposed and decided? Access to data by whole team? Remote participation?
- Impetus for task group was combination of our own interests as US researchers, and requests for input from the ITER Organization.
- Task group led by Rajesh Maingi (PPPL), Mike Walker(GA) , 8 other members from across MFE program.
- To date:
  - Gave ITER input on practices on US experiment workflow, from proposal to publication, and examples of data analysis (June 2013).
  - Gave ITER *draft* input on how US envisages experimental operation on ITER, as input to CODAC design reviews (Sept).
- Coming months: Broaden scope (eg, *How will, US organize itself?)* and community input (web site, web seminar). Produce final report.

MFE research in support of burning plasmas is – and needs to be – very active.

Results were highlighted in a recent contributed session at APS-DPP "Research in support of ITER"

USBPO got ~ 28 submissions for 15 slots. Much more relevant research in other presentations.

All talks now posted on USBPO web site. http://burningplasma.org

Broad range of topics including:

Integrated modeling S. Pinches, ITER Org.

Disruptions: C. Greenfield, GA for J. Wesley and R. Granetz, MIT for G. Olynk

ITER Diagnostics: Brent Stratton, PPPL

ICRF and with Metallic PFCs: S. Wukitch, MIT

Scenarios: J. Schweinzer, IPP Garching, J. Ko, NFRI Korea, F. Poli, PPPL

ELM Mitigation: L. Baylor, ORNL, N. Ferraro, GA

Divertor physics and integration: T. Petrie, GA, J. Lore, ORNL,

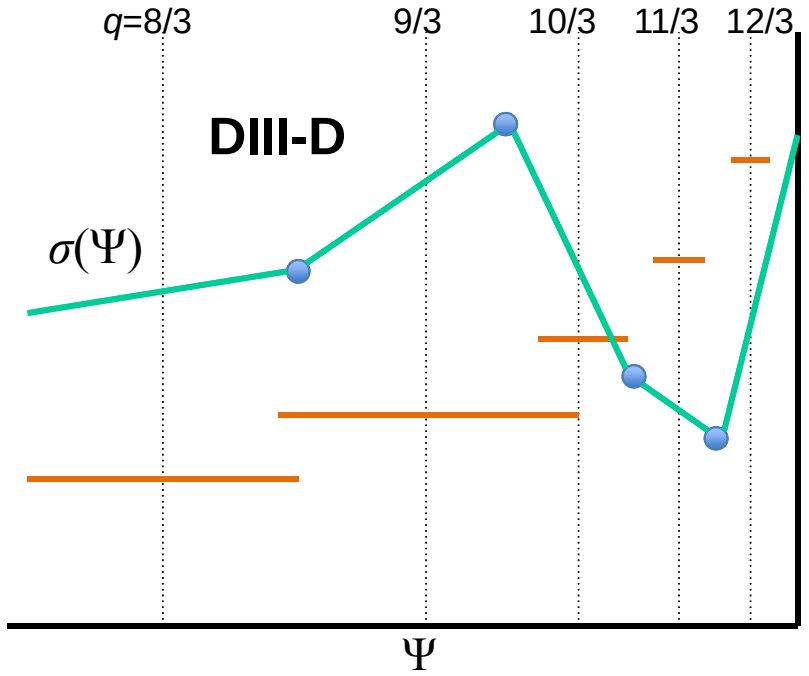
Plasma Control: J. Snipes, ITER, D. Humphreys, GA, D. Shiraki, Columbia

Will show a few examples, time permitting

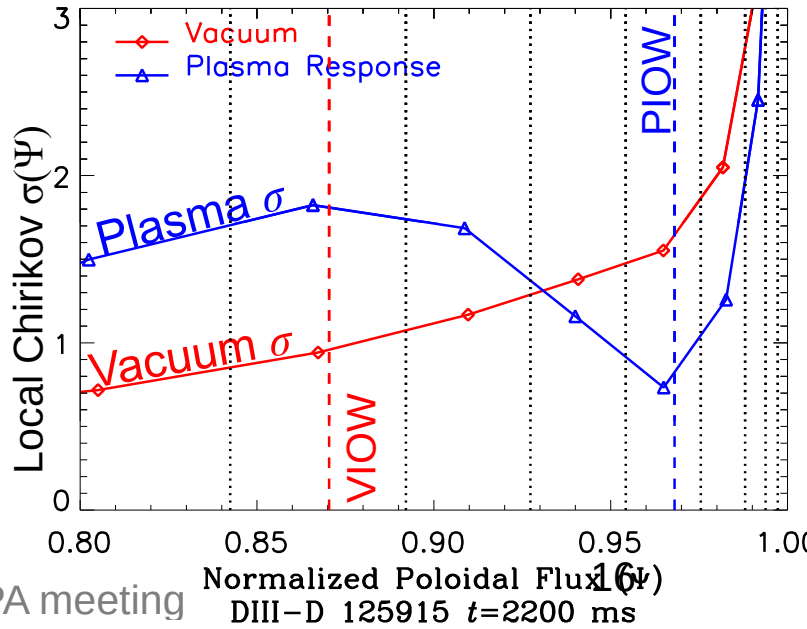
ELM Control – RMP models are being improved with plasma responses

Nate Ferraro, GA

- "Improved" ELM suppression criteria, with and without plasma response are being compared to DIII-D ELM suppression experiments.
- Used to predict suppression in ITER scenarios.



Metric	Threshold	Accuracy
Vacuum IOW	12.7%	63%
Plasma IOW	6.4%	70%
Vacuum σ_{ped}	1.55	89%
Plasma σ_{ped}	0.90	73%

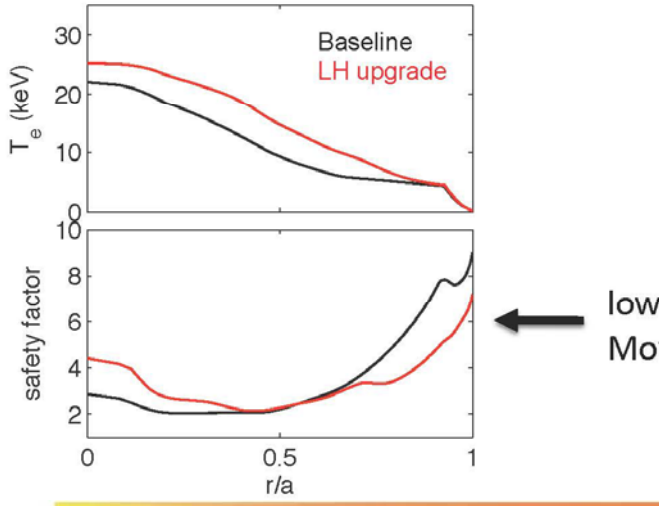


Integrated modeling looking ahead to H&CD upgrades for ITER steady state

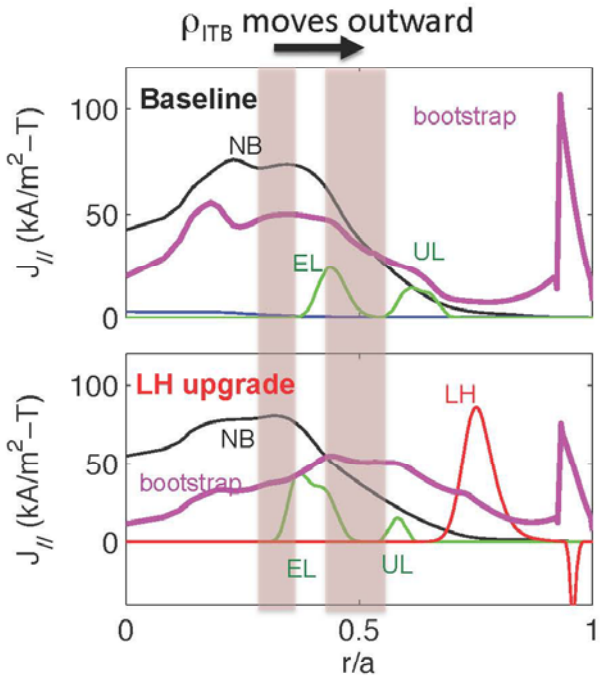
F Poli, PPPL

20 MW of coupled LH can enhance the plasma performance toward the ITER goals

	Baseline		LH upgrade
n/n_G	1.0	->	0.87
q_{95}	8.1	->	5.6
I_{NI}	6.4	->	8.2 MA
Q	1.7	->	2.9
β_N	1.77	->	1.78
H_{98}	1.38	->	1.42



lower q_{95}
Moves $\rho(q_{min})$ outward

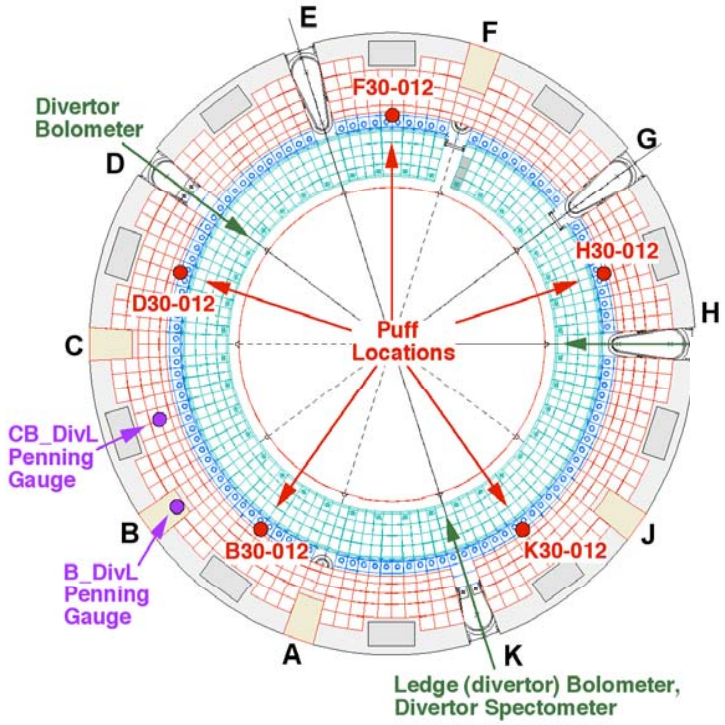


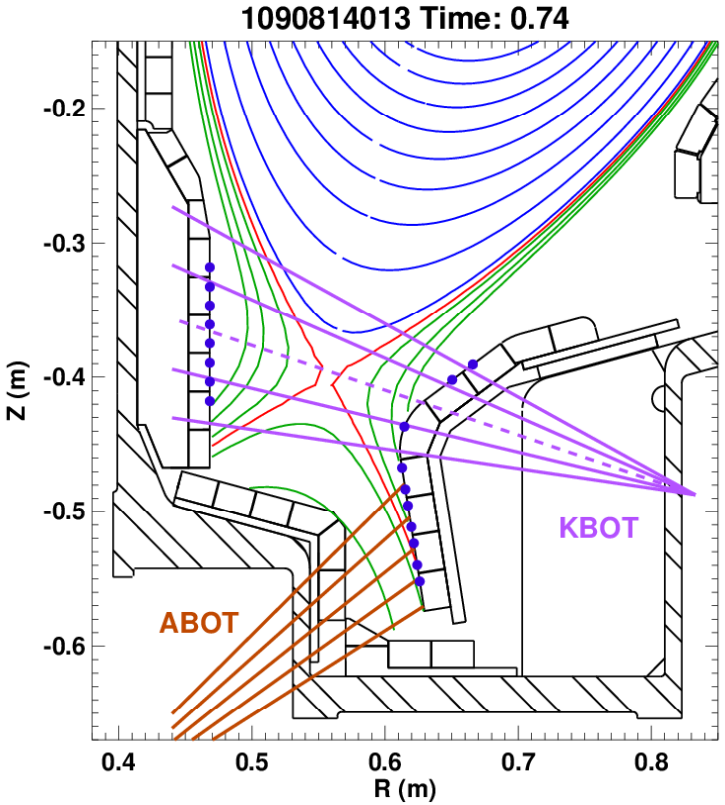
Francesca Poli 55th APS-DPP meeting, Denver CO, nov 2013 07/08

Impurity seeding experiments modelled in 3-D MC3-EIRENE

- ITER question: *How many gas valves will we need for seeding to uniformly reduce divertor heat load?*
- C-Mod ran experiments with toroidally localized divertor gas injection, arrays of diagnostics.

J. Lore (ORNL), modeling C-Mod experiments by M. Reinke (MIT)

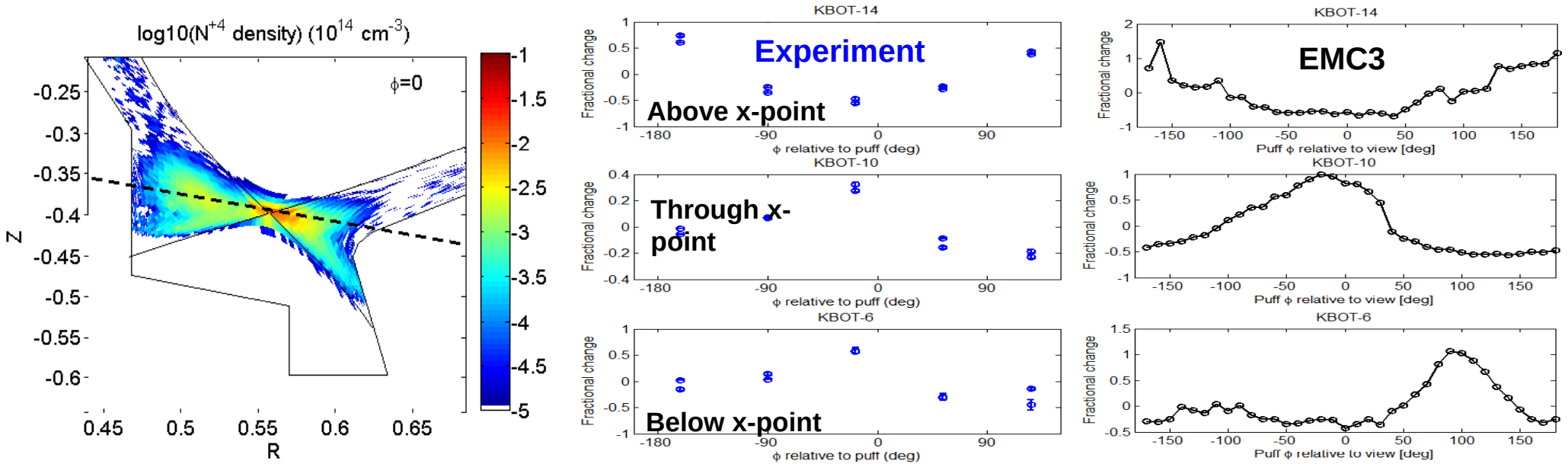




Impurity seeding experiments modelled in 3-D MC3-EIRENE

- **ITER question:** *How many gas valves will we need for seeding to uniformly reduce divertor heat load?*
- C-Mod ran experiments with toroidally localized divertor gas injection, arrays of diagnostics.
- New ORNL modeling reproduces many of the trends with puff location– some will require new physics.

J. Lore (ORNL), modeling C-Mod experiments by M. Reinke (MIT)

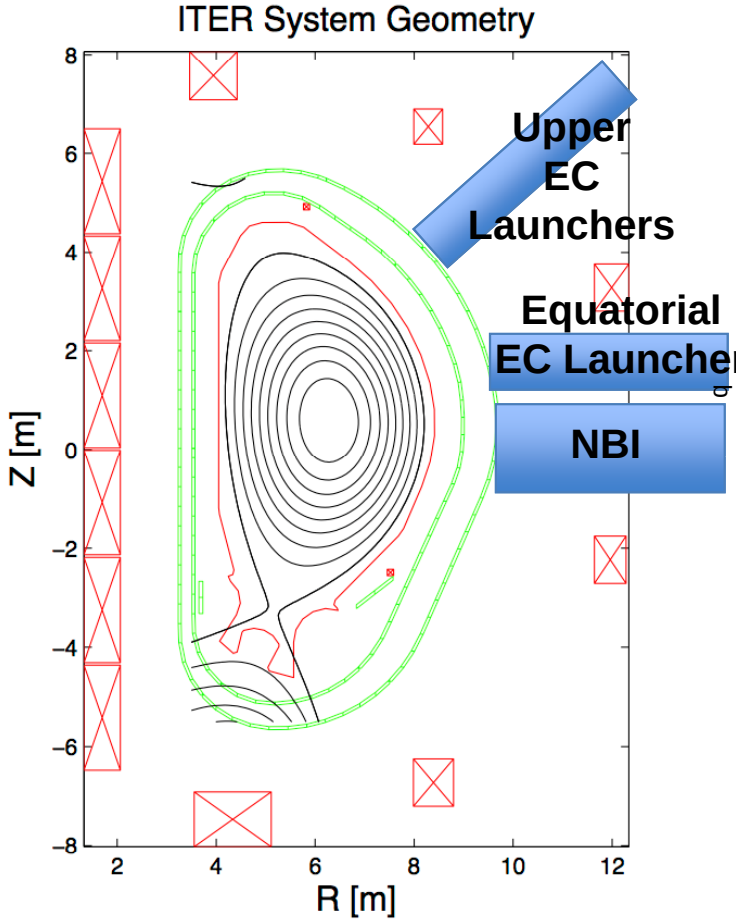


Control research involves new physics *and* mathematics

D. Humphreys, GA

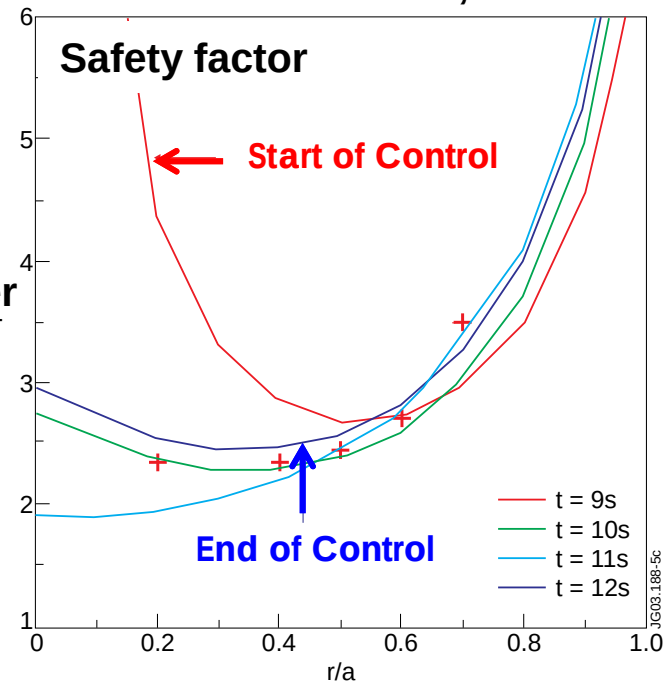
Eg CURRENT PROFILE CONTROL

- Actuators and Scheme:
  - ECH, NBI, density, loop voltage?
  - Multipoint q-profile control
  - Share EC system with MHD control
- **Status/Research Gaps:**
  - Some experiments done
  - ITER specific candidate not identified and demonstrated
  - Need robust actuator sharing scheme
  - Need integrated goals: scenario/kinetic and stability control



JET q-Profile Control

D. Moreau, CEA



- **q-profile regulated using LHCD, NBI, ICRH**

USBPO: MFE Research in Support of Burning Plasmas

- ITER is providing a strong focus in the US MFE program on the issues which need to be resolved to achieve burning plasmas.
  - Most of these are relevant to *any* fusion-scale facility (eg a Fusion Nuclear Science Facility). DEMO will have same and greater needs. Hence any 'vision for the future' requires solving BP issues.
- USBPO plays a role in supporting this research.
  - **Communicating** issues and progress to the US community.
  - **Coordinating** research where helpful.
  - **Preparing** for effective participation on, and benefit from, ITER.
- The actual research is conducted by US research groups, and depends on continued DOE support.
  - Has been declining in recent years as number of facilities, run weeks and supported researchers at all institutions decreases.
  - Strong MFE program is vital if US is to help ITER succeed, and ***"ensure the greatest benefit from burning plasma experiments"***

For more info or to join

- Web site www.burningplasma.org

- There you can sign up:
  - To become a member, researchers join one or more topical groups of interest.
  - Those outside US can become ‘associate members’
  - Anyone can receive monthly e-News.