Conceptual Design of the ITER Plasma Control System

J A Snipes

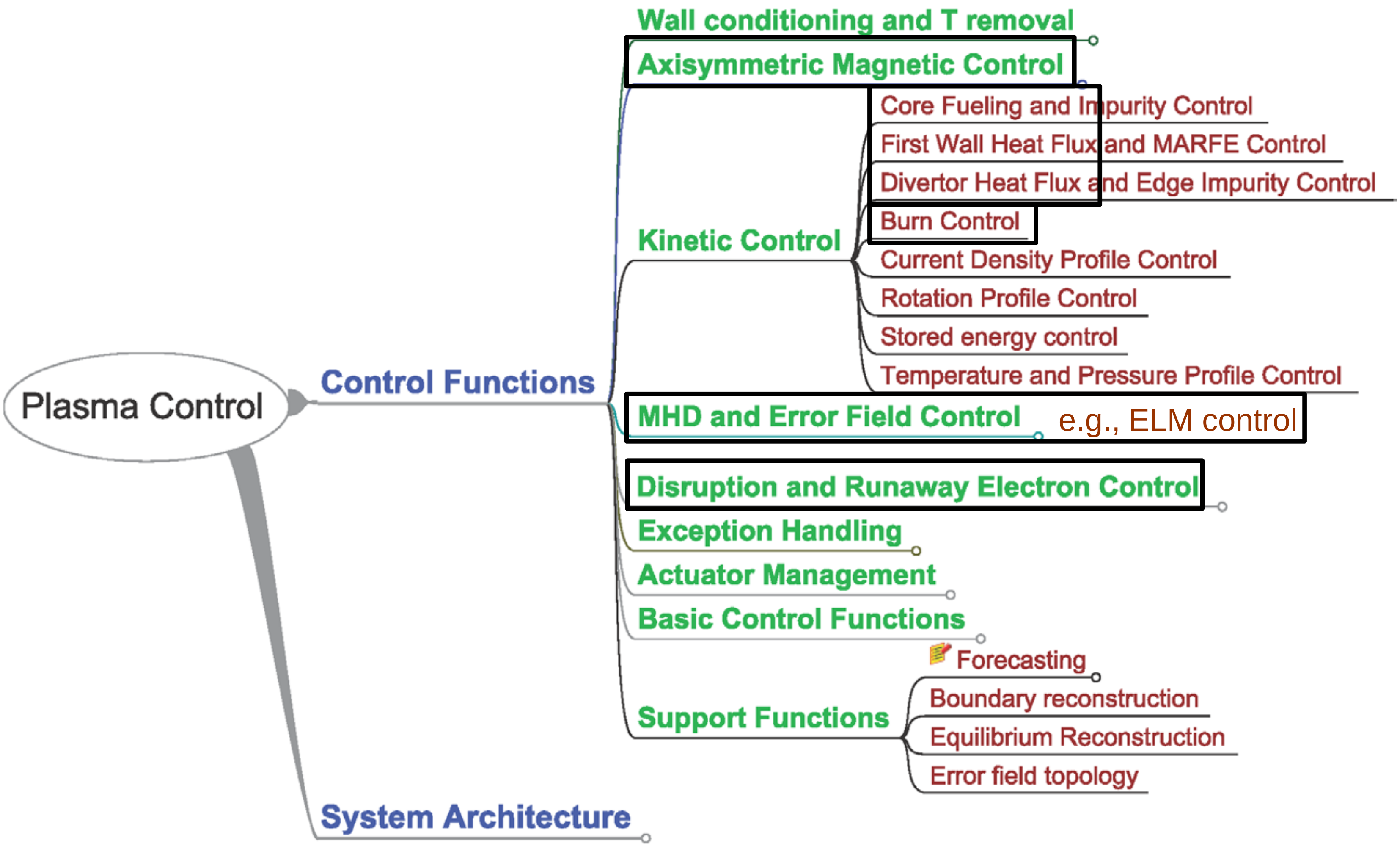
for the ITER PCS Conceptual Design Team

ITER Organization

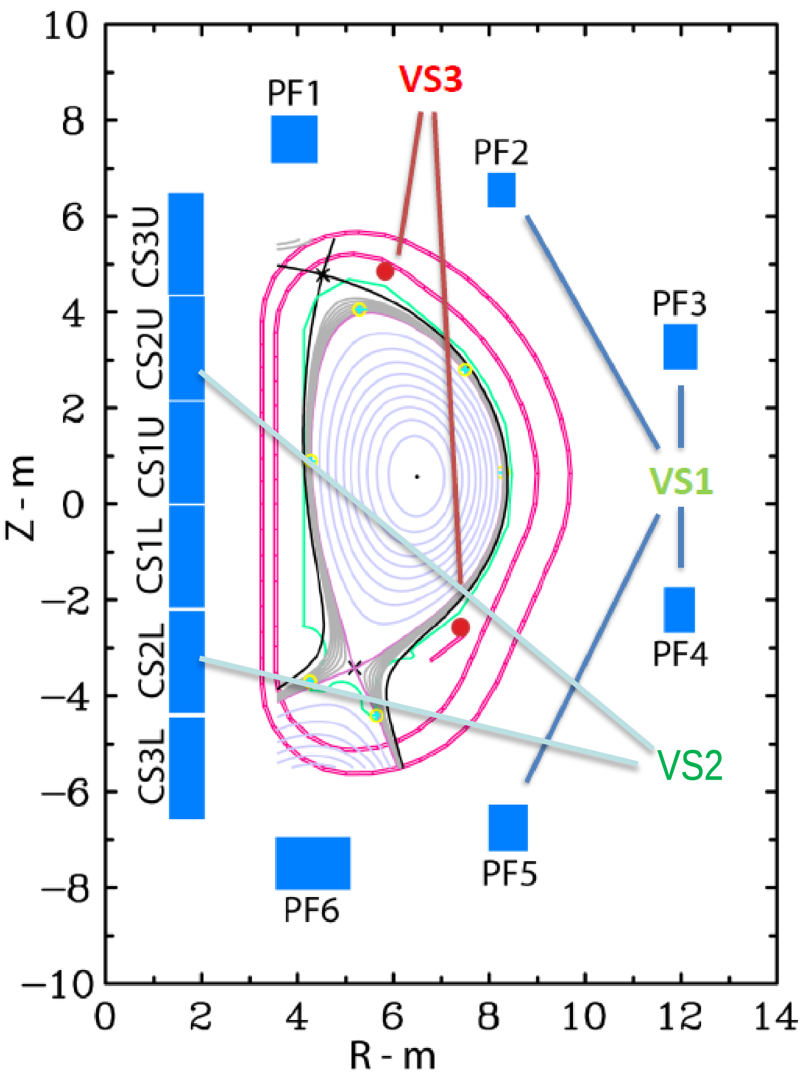
13115 St. Paul-lez-Durance, France

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

PCS Control Functions Breakdown Structure



Actuators for Axisymmetric Magnetic Control



ITER axisymmetric magnet system layout

PF1to PF6 poloidal field coils

CS1 to CS3 central solenoid coils (upper and lower)

VS1 dedicated power supplies for circuits combining PF2 to PF5

VS3 independent set of internal coils

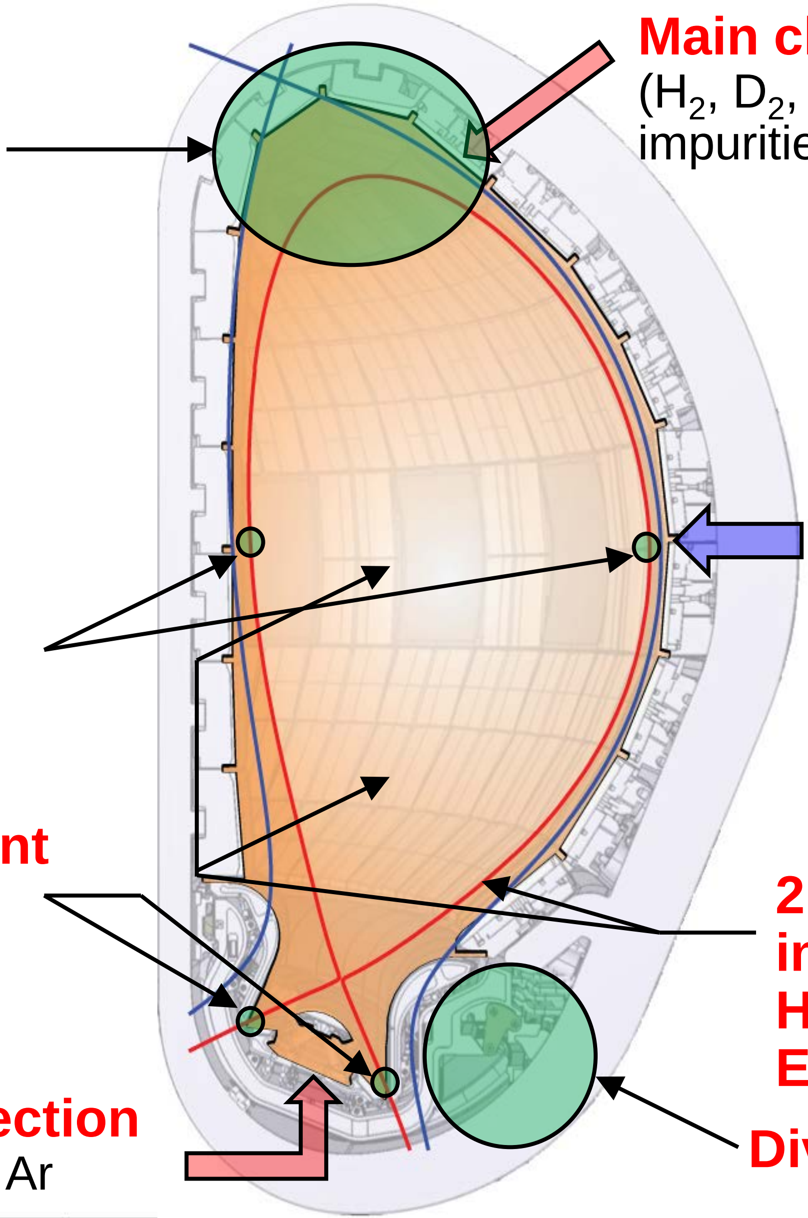
VS2* dedicated power supplies for CS2U and CSUL

*possible upgrade not in the baseline

Axisymmetric Magnetic Control ITER Specific Issues

- Long vacuum-vessel time constant: limitations with only VS1. Fast plasma event (disturbances) like H-L or L-H transitions may require in-vessel coils VS3
- Noise: acceptable level of noise for vertical control still needs to be determined
- Diagnostics: diagnostic capabilities including processed data due to the stringent requirements. Risk of diagnostic failure.
- Coupling: between control schemes and actuator sharing
- Machine protection: engineering limits pose stringent requirements on control. To avoid exceeding thermal load limits at the first wall/blanket requires accurate control of the plasma shape and position.
- Plasma initiation: null quality and reliability
- Vertical stabilization: analyses show that VS1 and VS1+VS2 will not allow vertical instantaneous uncontrolled displacement larger than a few centimeters (~5). VS3 allows up to ~16cm instantaneous uncontrolled vertical displacement.

Actuators for Fuelling and Heat Flux Control



Plasma shape, vertical position for secondary divertor heat flux control

Main chamber gas injection
(H_2, D_2, T_2, He and extrinsic impurities N_2, Ne, Ar, ^{3}He)

Auxiliary heating power

Main chamber wall gaps

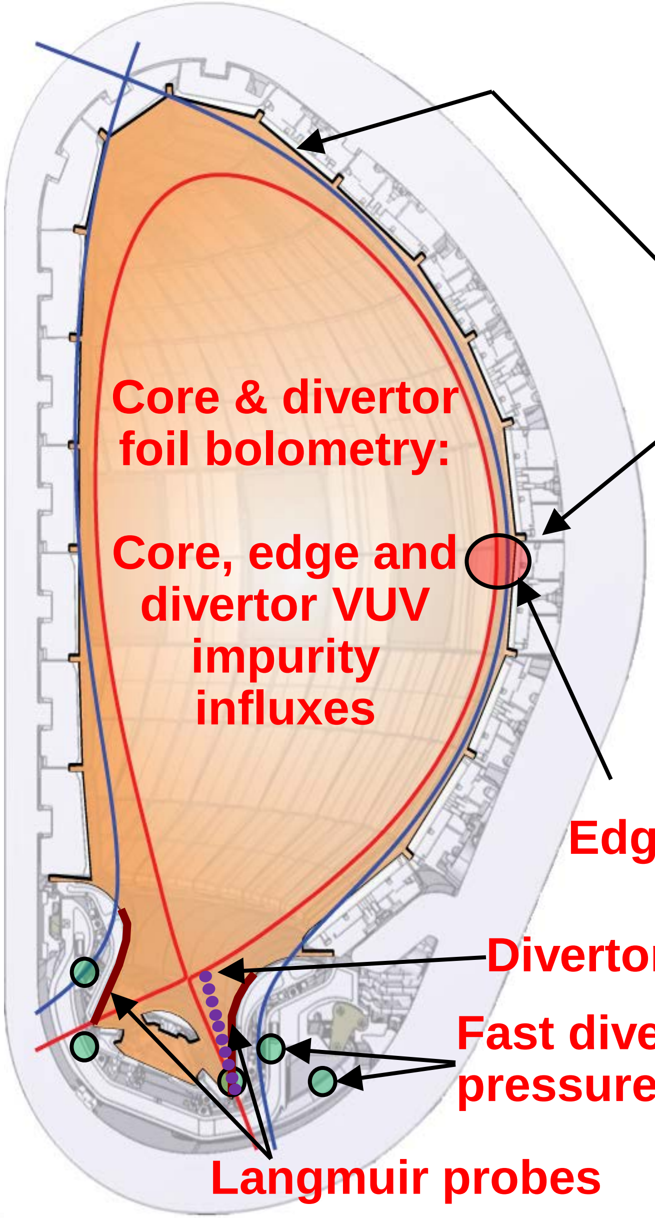
Strike point control

2 HFS and 1 LFS pellet injection locations, < 16 Hz fuelling + < 60 Hz ELM-pacing

Divertor gas injection
D_2, H_2, He, N_2, Ne, Ar

Divertor cryopumping

Sensors for Heat Flux Control



Core & divertor foil bolometry:

Core, edge and divertor VUV impurity influxes

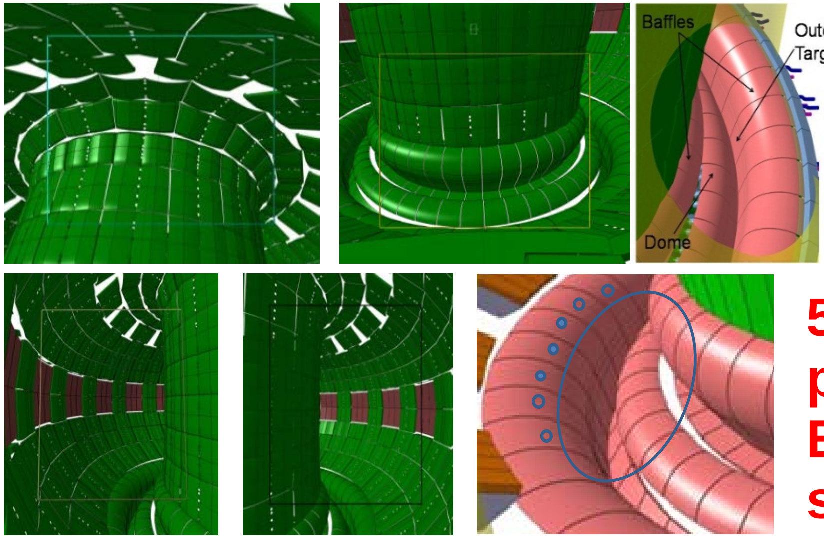
Edge reflectometry

Divertor TS

Fast divertor neutral pressure gauges

Langmuir probes

Extensive IR/VIS views: → likely >90% coverage at outer target with high enough resolution for control. Main chamber views: 85-100% FW coverage

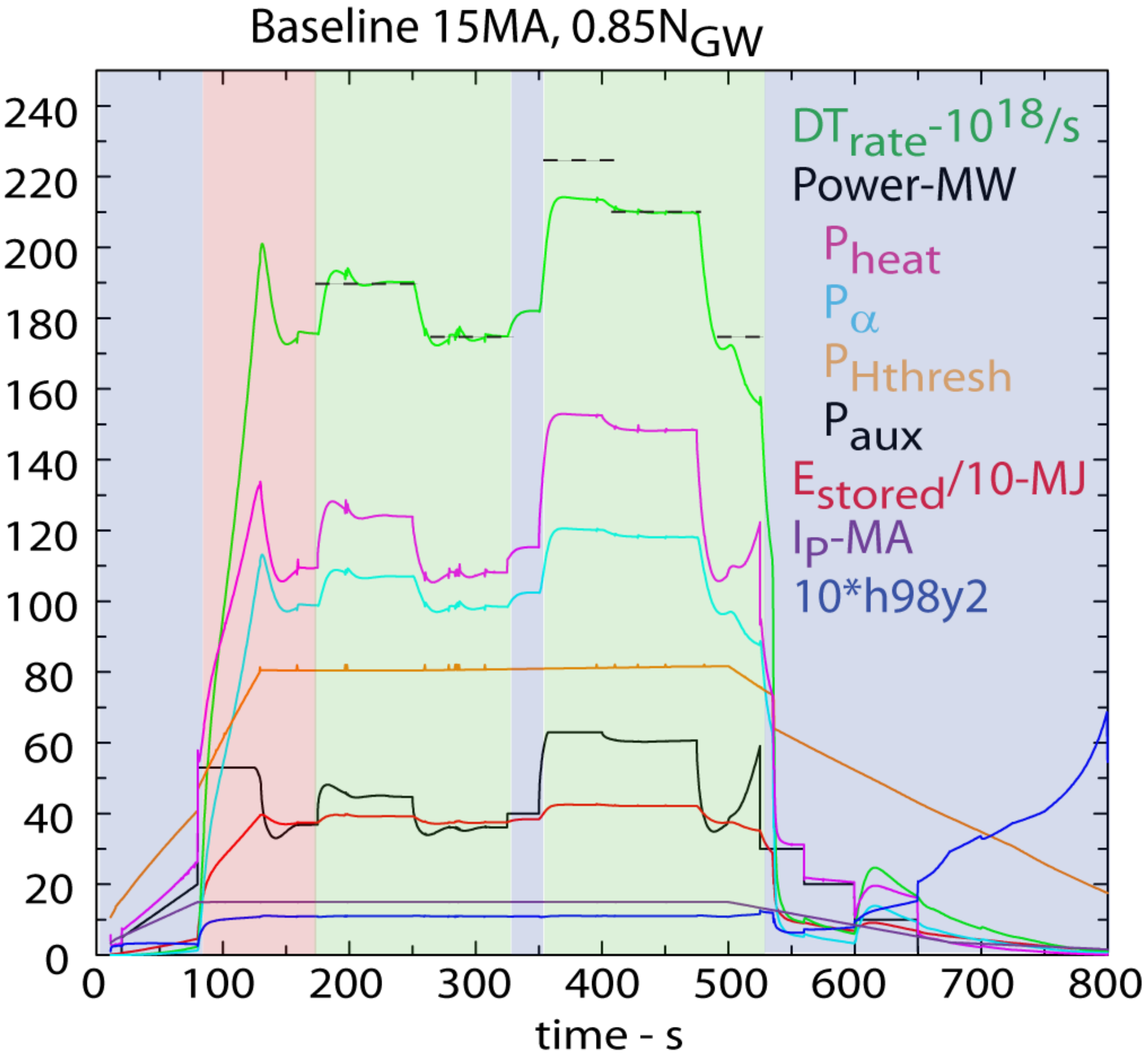


5 UPPER port and 4 EQ port systems

Controlling Access, Maintaining, and Exiting the Fusion Burn

- Fusion cross-section dependence on the T_i profile is stronger than linear – provides some burn control
- Access to H-mode and fusion burn
  - Separate core and edge fuelling control for L-H transition and D/T mix control
  - Pressure profile control at L-H transition to avoid instabilities and disruptions
- Fusion power dominates auxiliary heating power near Q~10 ➔reduced control
  - n_e , T can have different profiles so may achieve control via pressure
  - May be able to control species mix (density and fuelling control) slowly
- Exit from burn and termination of H-mode sensitive to profiles
  - Contribute to the control of vertical stability (e.g. l_i along with elongation)
  - Maintain H-mode until proper time for H-L transition
- Time scales ~10% of τ_E~1-5s with similar accuracy as in ramp up
  - fusion profiles measurements good to 10% at high neutron rate

CORSICA simulation of fusion burn control using auxiliary heating and simple PID controller: 15MA baseline, Q=10 scenario



- No burning tokamak yet so use simulation

Control in shaded areas:

- Pre-programmed P_{aux}
  - ramp during I_P ramp to limit power to divertor
  - Turned off feedback
  - Ramp down
- Stored energy feedback control (PID) for access to burn
- Neutron reaction rate feedback for burn control (PID)
  - neutron diagnostic
  - set points - - - - - -

MHD and Error Field Control Function Overview

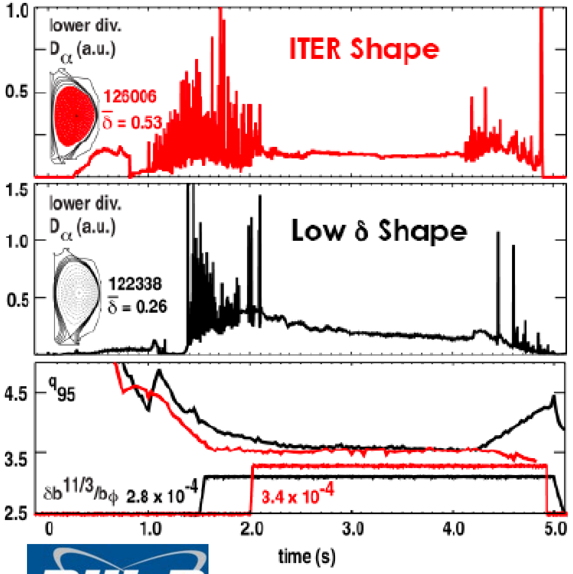
	Control Type	Actuators
NTM control	Feedback on the mode Modify operating point	ECRF
RWM control	Feedback on the mode	External correction coils, in-vessel ELM coils
ELM Control	ELM regime control ELM triggering	Pellet-pacing, in-vessel ELM coils
Sawtooth control	Sawtooth delay or trigger Sawtooth regime control	ICRF, ECRF
TAE control	Modify operating point	Shaping, ECRF?
Error field control	Adjust	External correction coils, in-vessel ELM coils

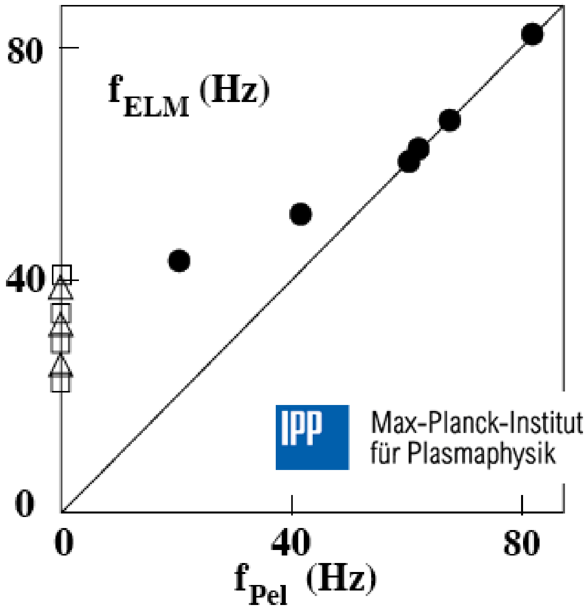
ELM Control is Critical to Reduce Wall/Divertor Heat Load

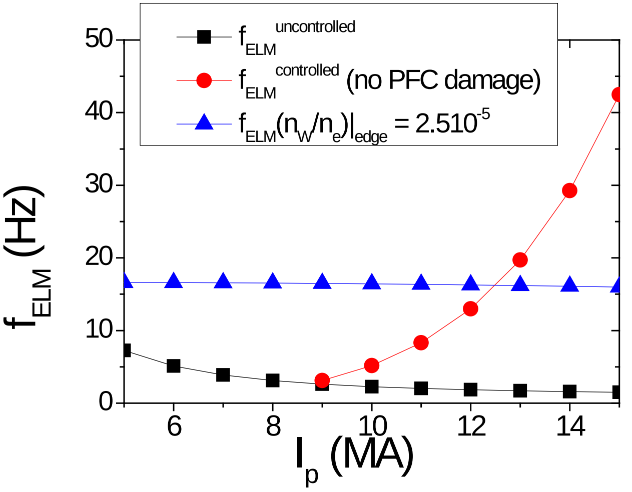
DIII-D Magnetic Control

AUG Pellet Pacemaking

Required f_{ELM} in ITER



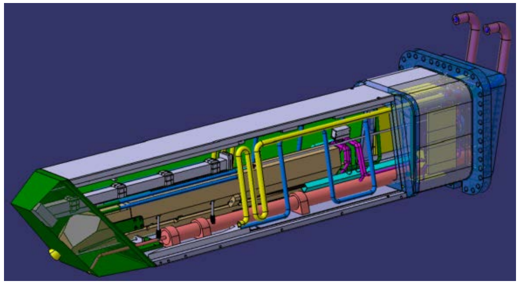




A Loarte et al, IAEA-2012

- ELM control is needed to substantially reduce divertor heat loads
- ITER will use in-vessel ELM coils and pellet pacing for ELM control
- ELMs may be acceptable in ITER up to I_p = 6 – 9 MA but at 15 MA heat loads must be reduced by a factor of 10 – 20
- ELM frequency must be > 16 Hz to limit W accumulation in the core

Disruption/RE/VDE Prediction, Avoidance, Mitigation & Control



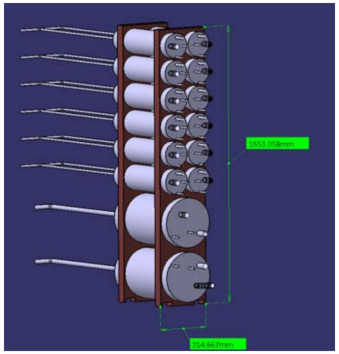
- **Detailed assessment of impacts indicates that:**

  Very high performance of the following three systems must be achieved simultaneously to meet ITER requirements

  - Disruption rate (avoidance)

  - Prediction success rate (⇒ *Forecasting*)

  - Disruption Mitigation System (DMS) performance



- **Separate systems for disruption and runaway electron mitigation**
- **Total DMS latency time (including gas delivery, cooling) < 20 ms**
- **Considering Ar, Ne gas or shattered pellet or Be pellet injection**
- **DMS profiles will be updated in real-time by the PCS every ms to adjust gas or pellet species mix, size, flow rate etc depending on plasma current and stored energy**

Conclusions

- This has been a brief overview of the ITER PCS Conceptual Design
- Dave Humphreys will cover the more novel aspects of the ITER PCS Conceptual Design next
- The Conceptual Design gives a broad overview to ensure that the PCS and the planned diagnostics and actuators will have the functionality necessary to carry out all foreseen control functions, within known physics uncertainties
- Many of the basic control algorithms used on existing devices can be straightforwardly adapted to ITER
- Continued R&D on existing devices is required to develop a number of the more advanced plasma control algorithms required for high performance ITER operation – e.g., 1st wall and divertor heat flux control, disruption and runaway electron prediction, avoidance, and mitigation