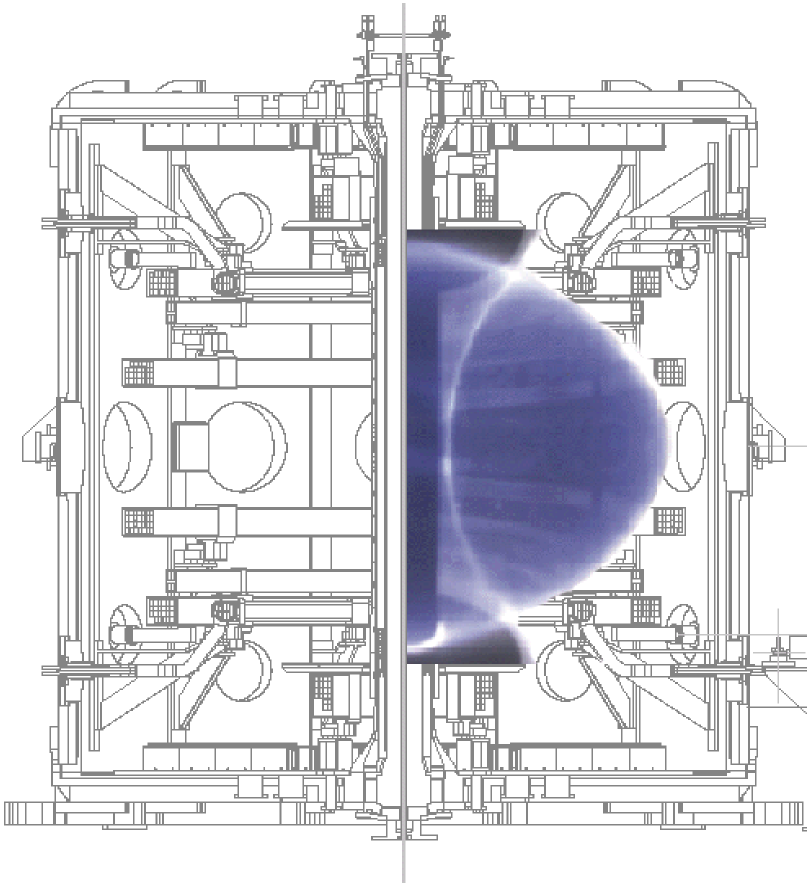
The MAST Research Programme

Rob Akers on behalf of the MAST team - 24th June 2002, NSTX Five Year Plan Workshop
UKAEA Culham Science Centre, Abingdon, Oxfordshire, OX13 3DB, UK



This work was funded by the UK DTI and by EURATOM. The MAST NBI system was provided by ORNL, the NPA by PPPL and EFIT by General Atomics. Pellet injection work is being carried out in collaboration with FOM.

- The MAST mission
- The MAST Device

Programme to date

- H-mode access
- Edge Stability (ELMs)
- Global Confinement
- Exhaust
- Future Machine Upgrades

Forward Programme

The MAST mission

Main directive: Address 3 key ITER issues

Confinement:

H-mode Access
- minimisation of threshold conditions
- reduction of uncertainties in ITER predictions (data scatter, degeneracies)

H-mode Confinement
- good confinement at high density
- good confinement with tolerable ELMs

Stability(sustainment):

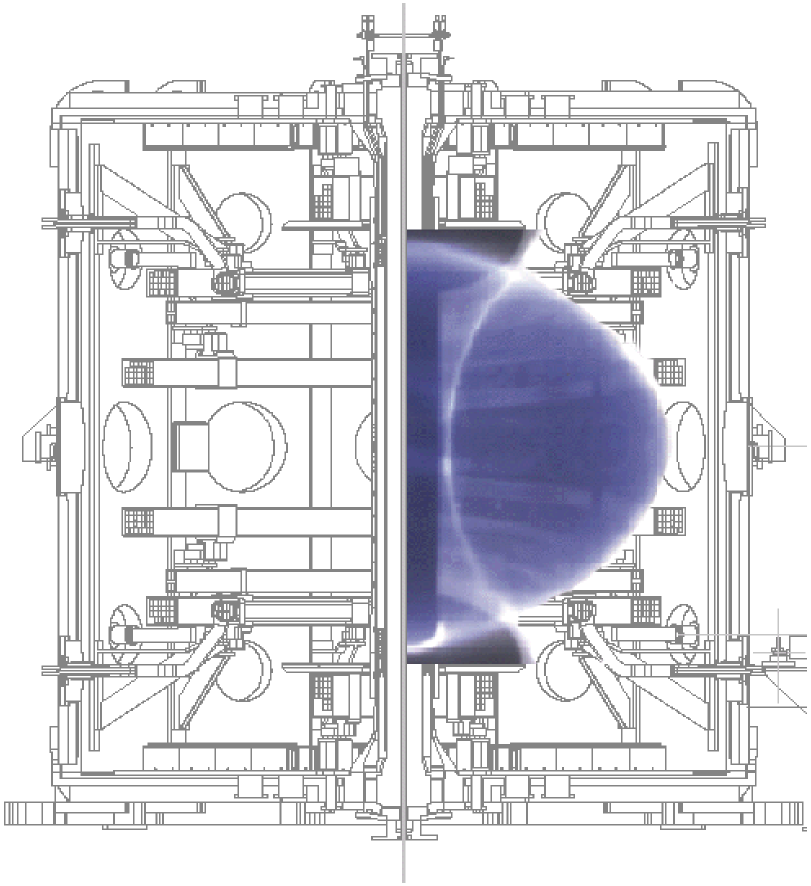
Control/mitigation of neo-classical tearing modes (high beta access)
Scaling of edge pedestal parameters and ELMs
Plasma terminations and halo currents

Exhaust:

Reduction of divertor loading and impact of ELMs
Improved characterisation of the plasma boundary and impact on scalings for ITER.

The MAST Device

MAST Parameters

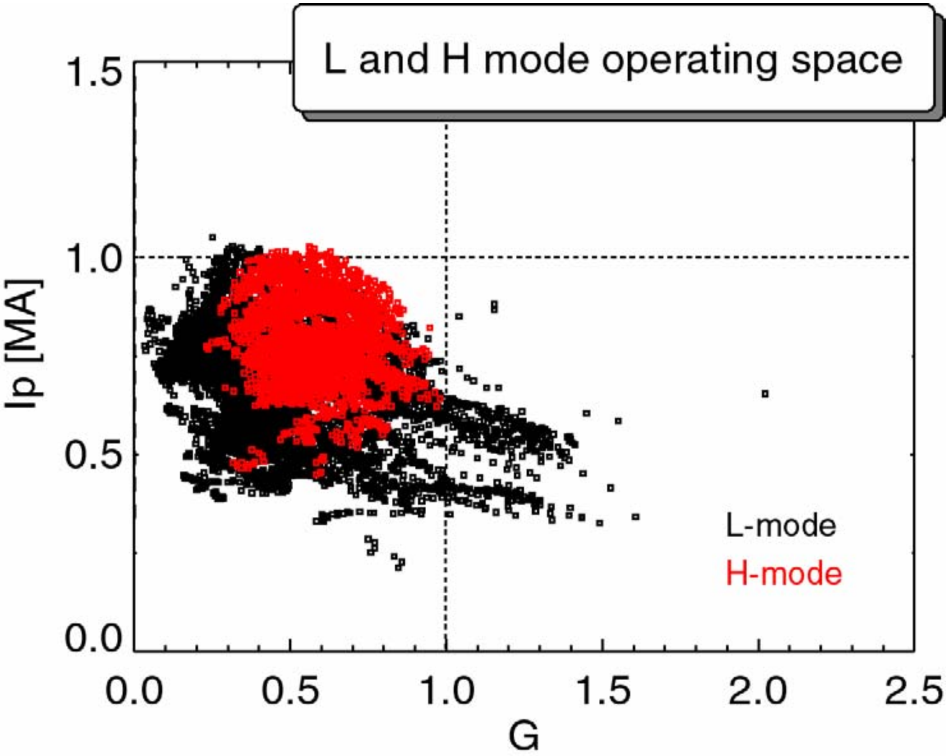


	Design	*Achieved*
Major radius	0.85 m	0.85 m
Minor radius	0.65 m	0.65 m
Elongation	2.5	2.4
Triangularity	0.5	0.5
Plasma current	2 MA	1.2 MA
Toroidal field	0.51 T	0.51 T
NBI heating	5 MW	1.8 MW
RF heating	1.5 MW	0.8 MW
Pulse length	5 s	0.5 s

16 Apr 02 ⇒ 3MW into calorimeter
18 Apr 02 ⇒ >2MW into plasma

H-mode access

H-mode access



Shots 4100-4600
(Summer 01)

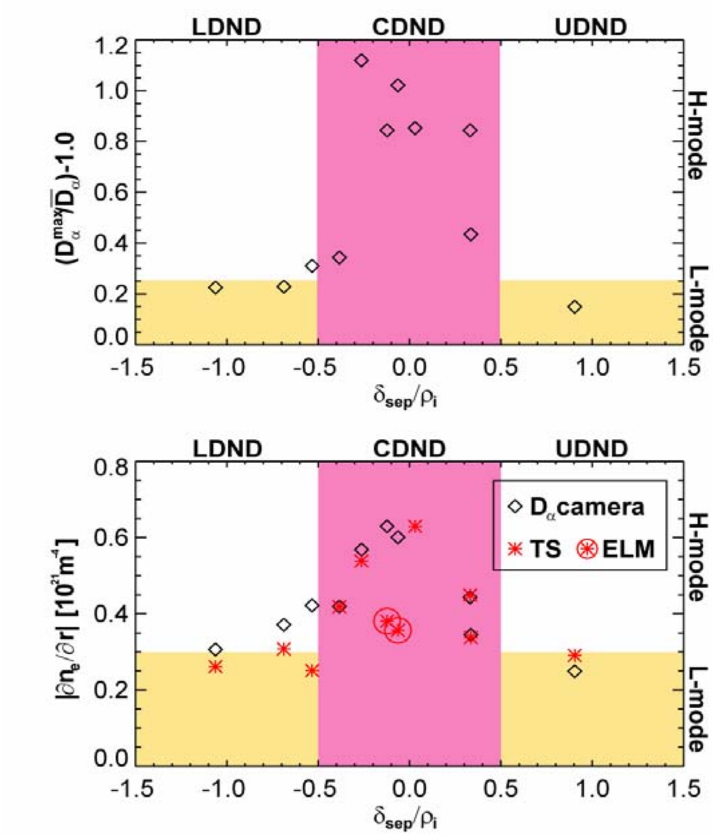
Approximately 35% of all ‘shots’ in MAST Summer 2001 campaign contained a long H-mode phase

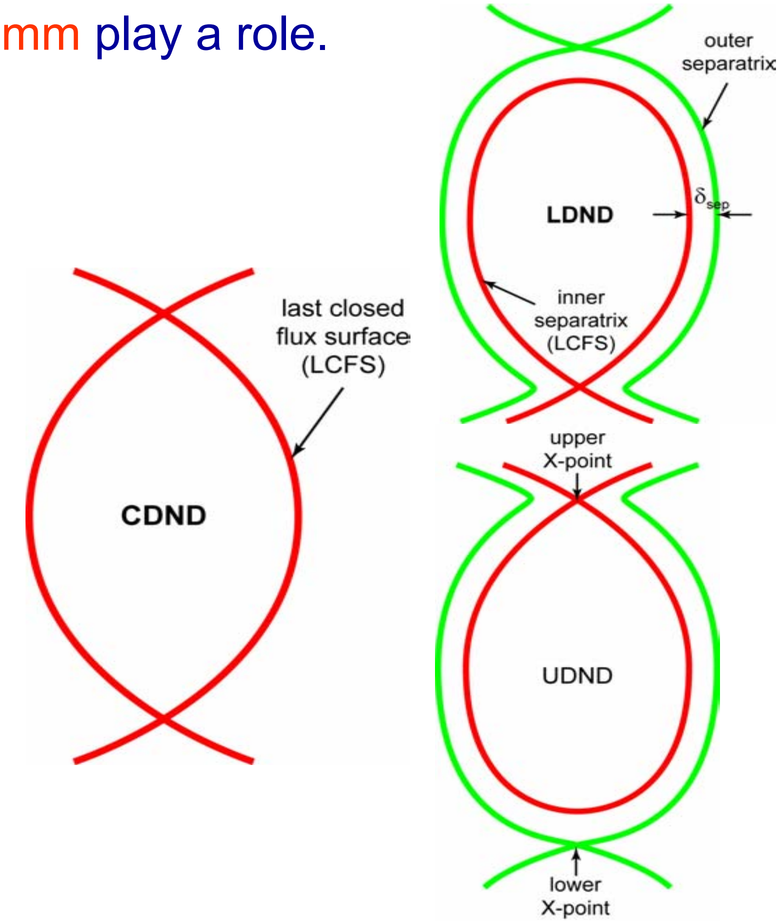
H-mode operating space extended up to I_p>1MA, G~1

Ip>1MA at G>1 limited by need to be cautious with current solenoid

Minimisation of P_{th} via optimisation of geometry

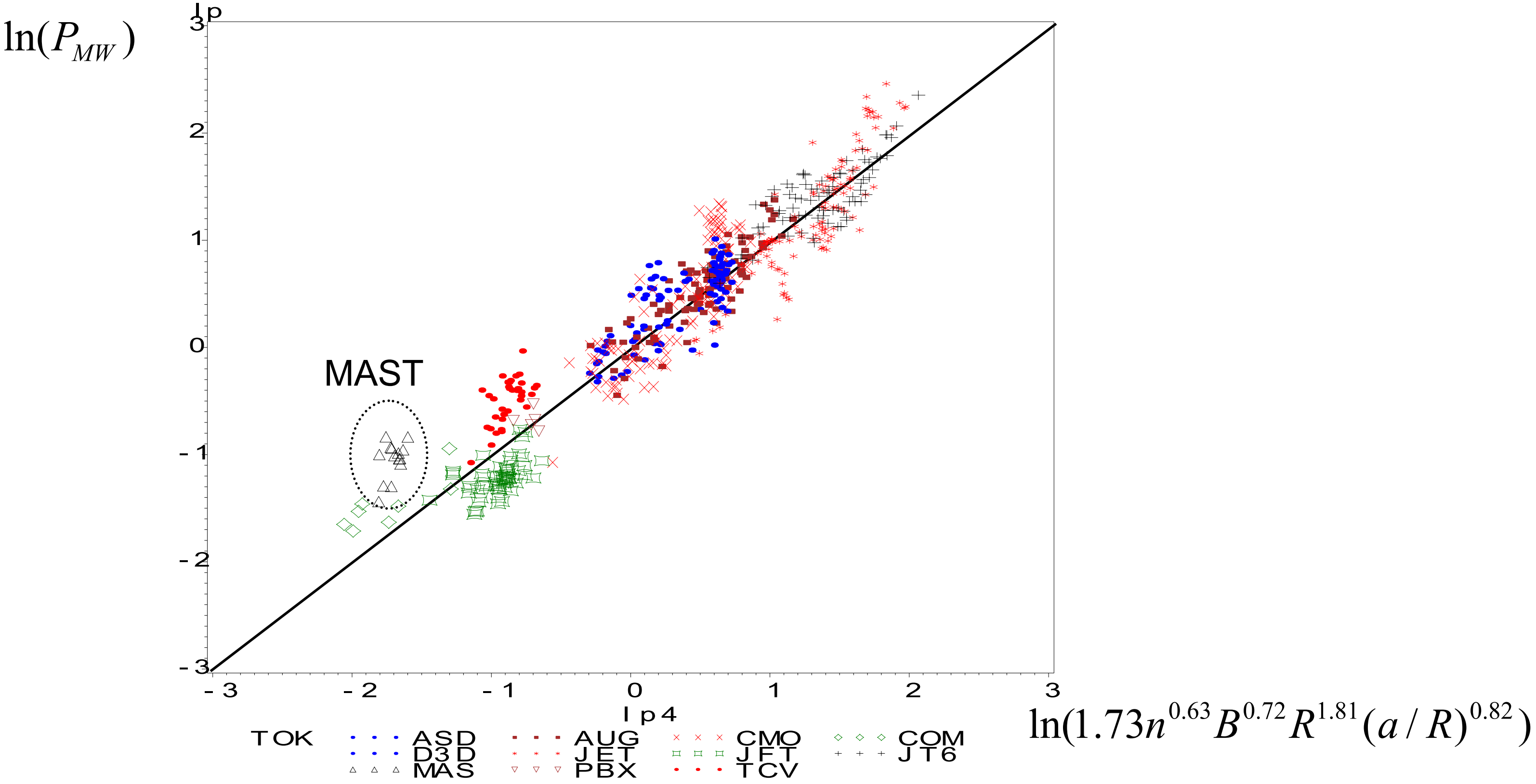
Subtle changes in the magnetic geometry are important for H-mode access - changes of the order $\rho_i \approx 6$ mm play a role.





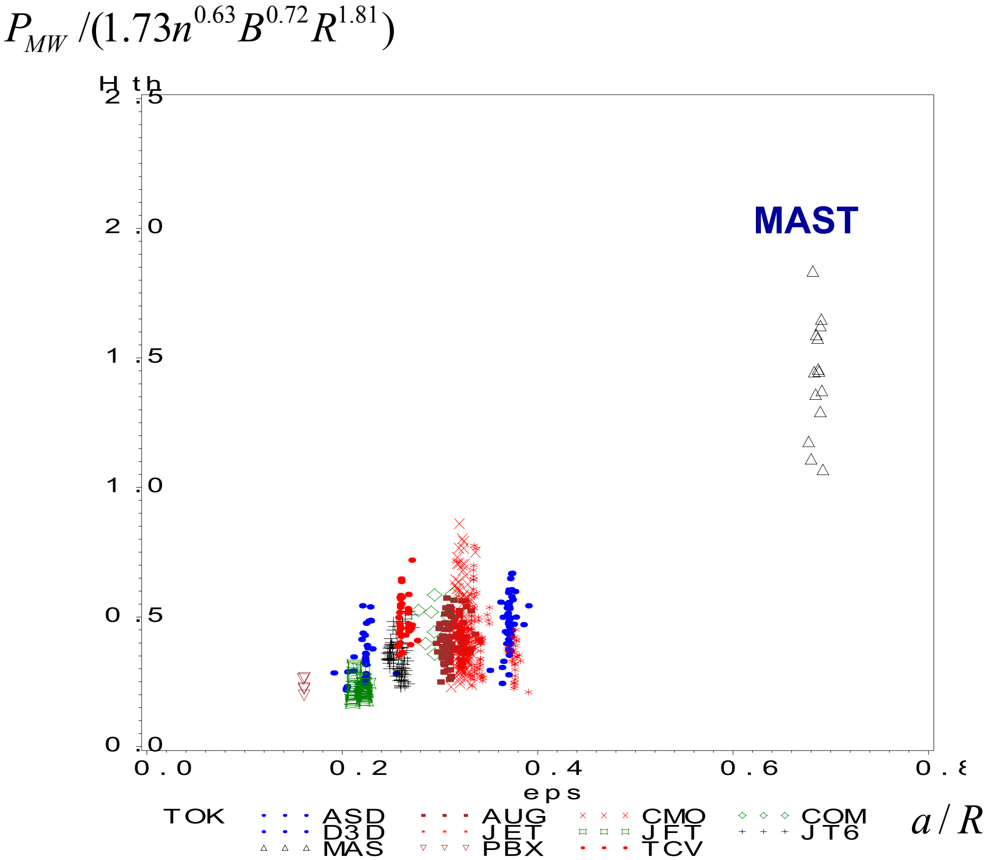
May be linked to changes in the SOL and influence on radial electric field

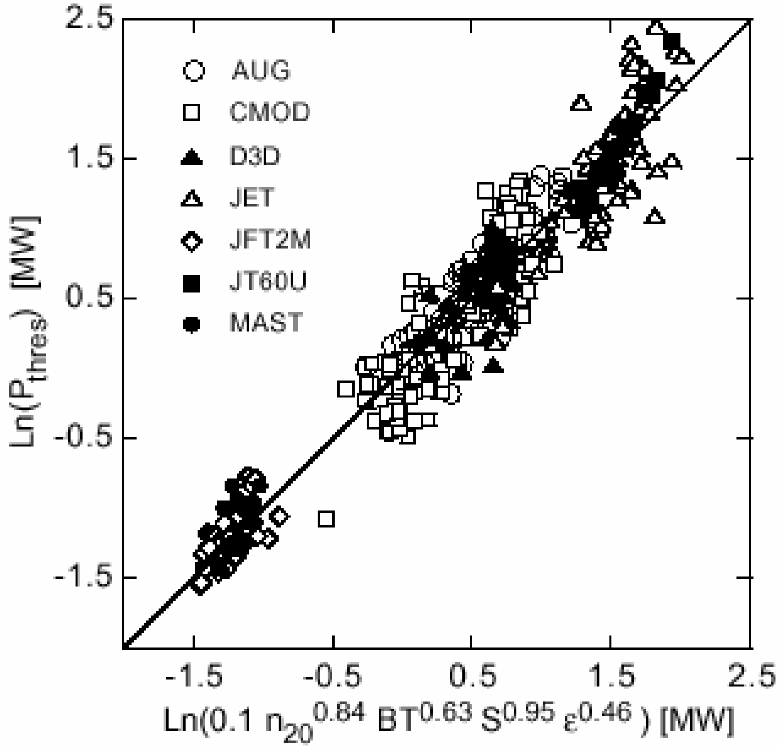
H-mode power threshold scaling (1)



F Ryter et al 2001

H-mode power threshold scaling (2)





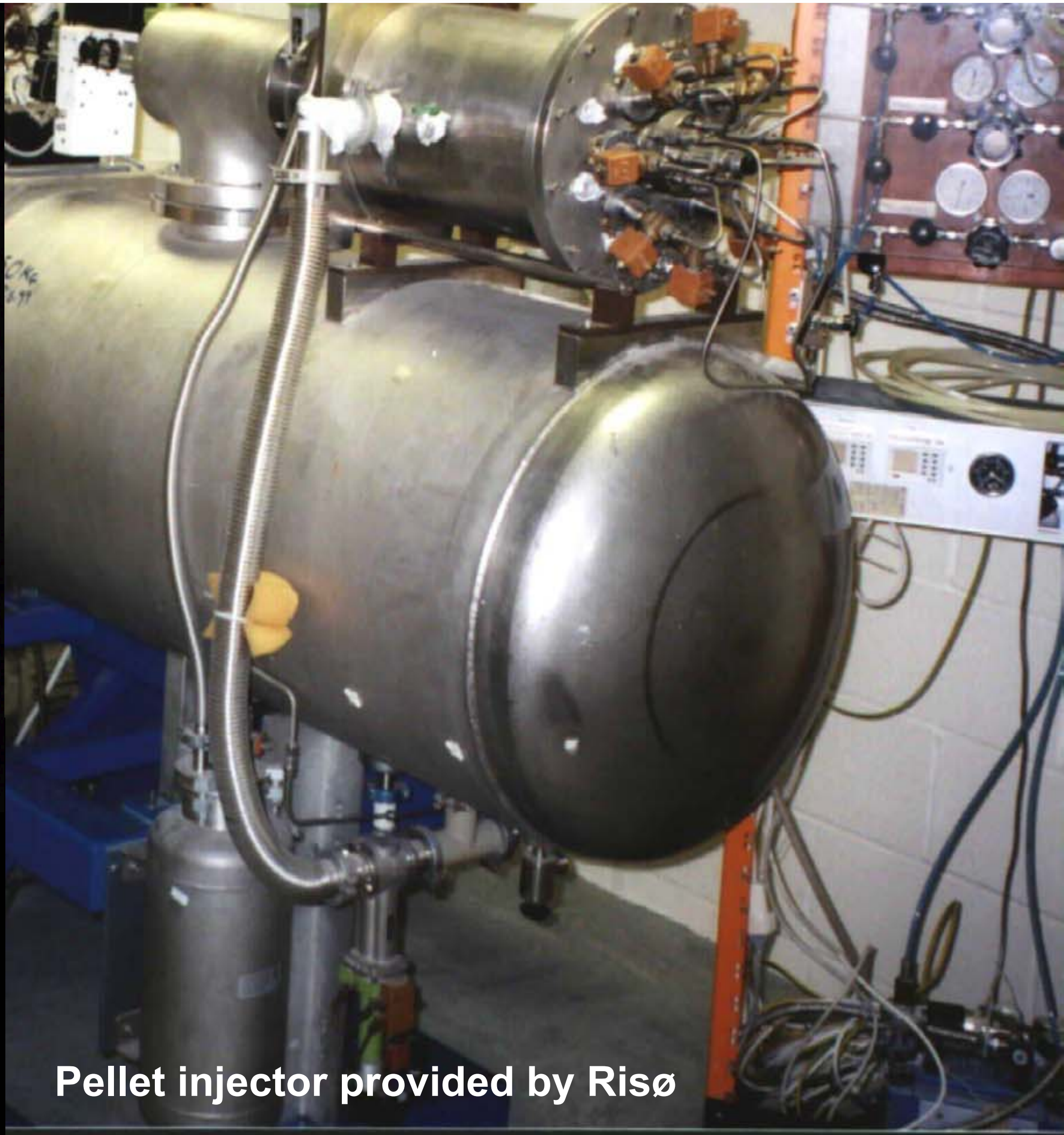
MAST data doube the range of a/R

Data favours P_{th}~ aR rather than P_{th}~ R^2

Measured threshold loss power vs predicted H-mode threshold scaling including latest MAST data (Snipes et al 2002)

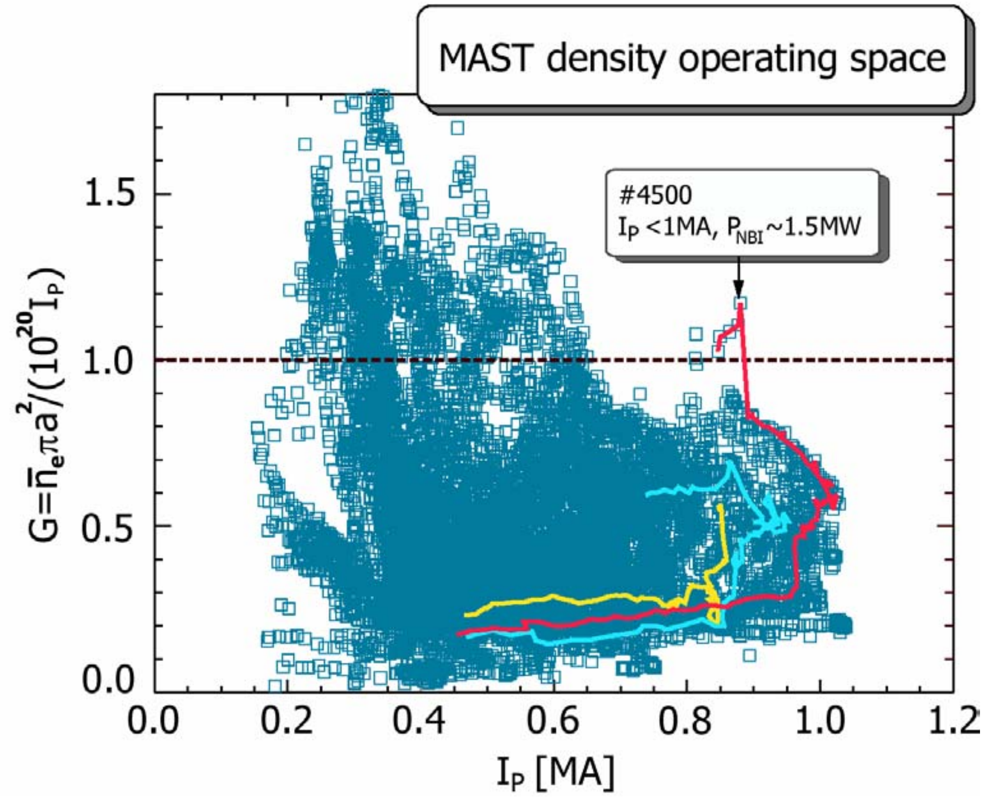
Fuelling optimisation - inboard gas puff and pellets

Up to 8 pellets per shot, D_2 drive gas
Vp ~ 400-600 m/s
Particle inventories ~0.5-2.0x10 ^{20}
Testing using LFS launch
Independent barrel controllers installed



Pellet injector provided by Risø

Greenwald limit easily exceeded

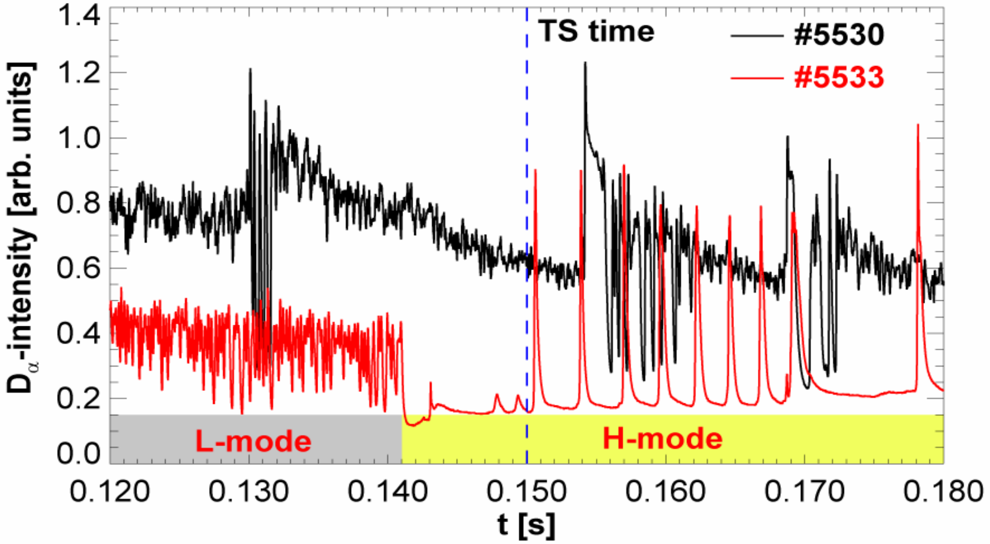


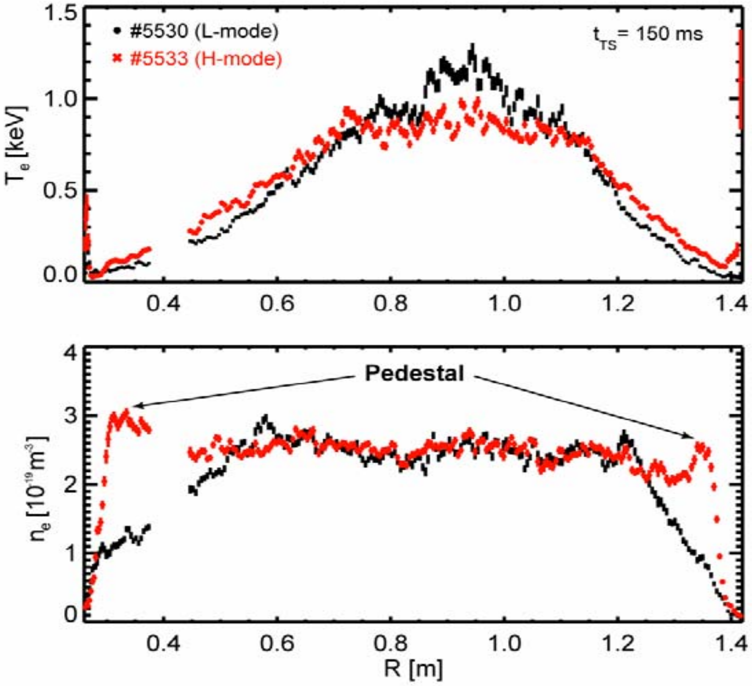
Inboard gas puff (+ increase in P_{NBI}) has increased G>1 regime to 0.8 MA (~0.5 MA in 2000)

G>1 extended up to 0.9 MA after ~5 shots using pellets

Fuelling source influnces H-mode

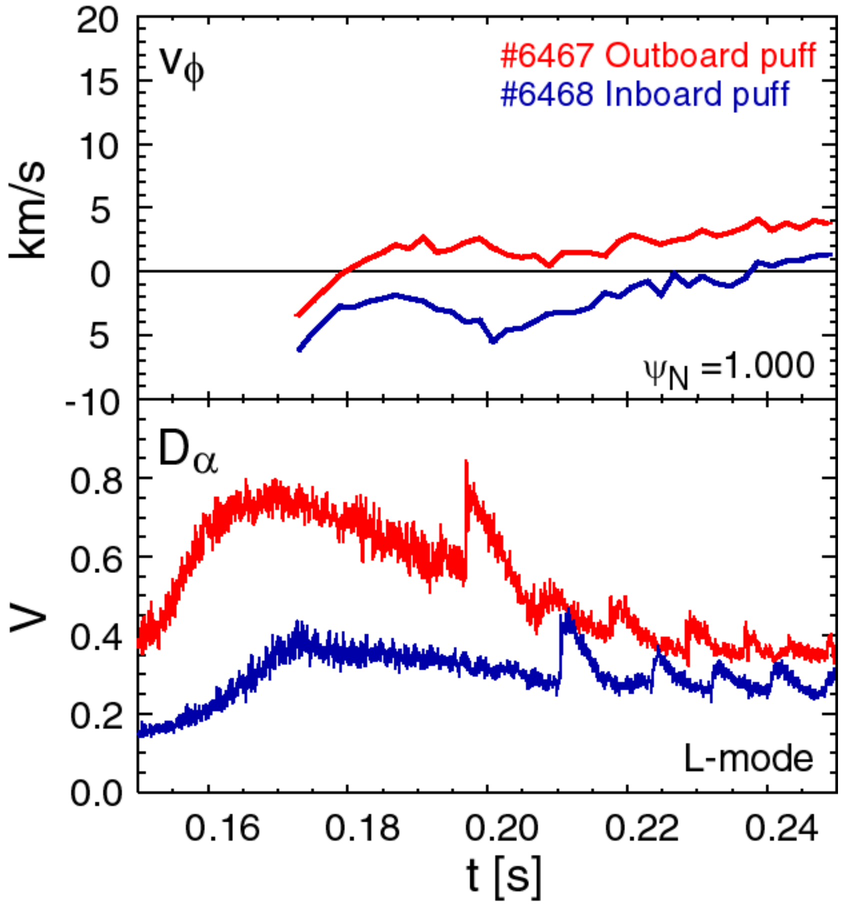
- Outboard fuelling
- Inboard fuelling





Theory suggests improved H-mode with inboard fuelling may be linked to influence of neutrals on toroidal rotation - experimental confirmation has just started.

Fuelling source influences H-mode



Poloidal localisation of D^0 may impact edge plasma flow and E_r

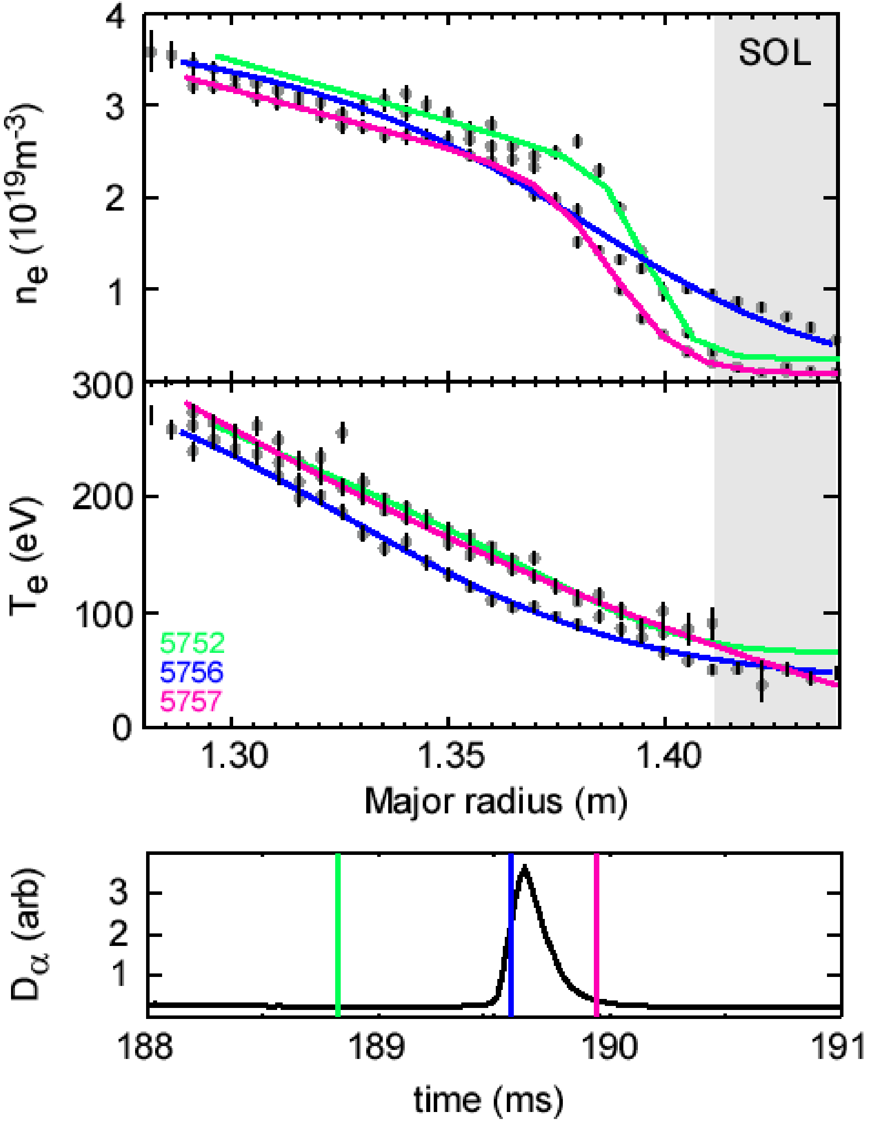
- T. Fulop, P. Helander, P.J. Catto, to be submitted to PoP

Measurements of He^+ ion flow in L-mode plasmas confirm impact of inboard vs outboard puffing

Predicted v_f variation comparable with v_f^{meas} in H-mode for inboard and outboard puffing

Edge Stability (ELMs)

ELM losses appear convective



300-point TS shows steep density

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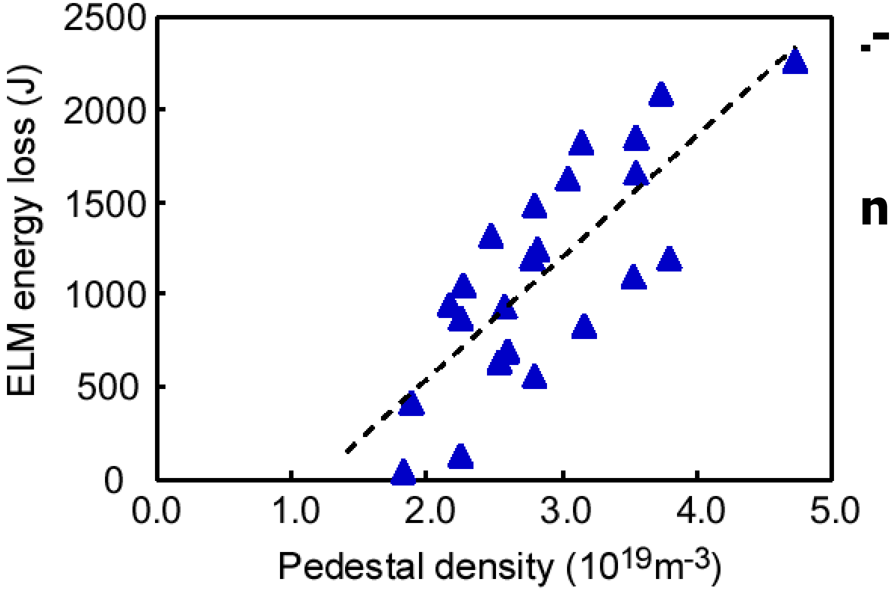
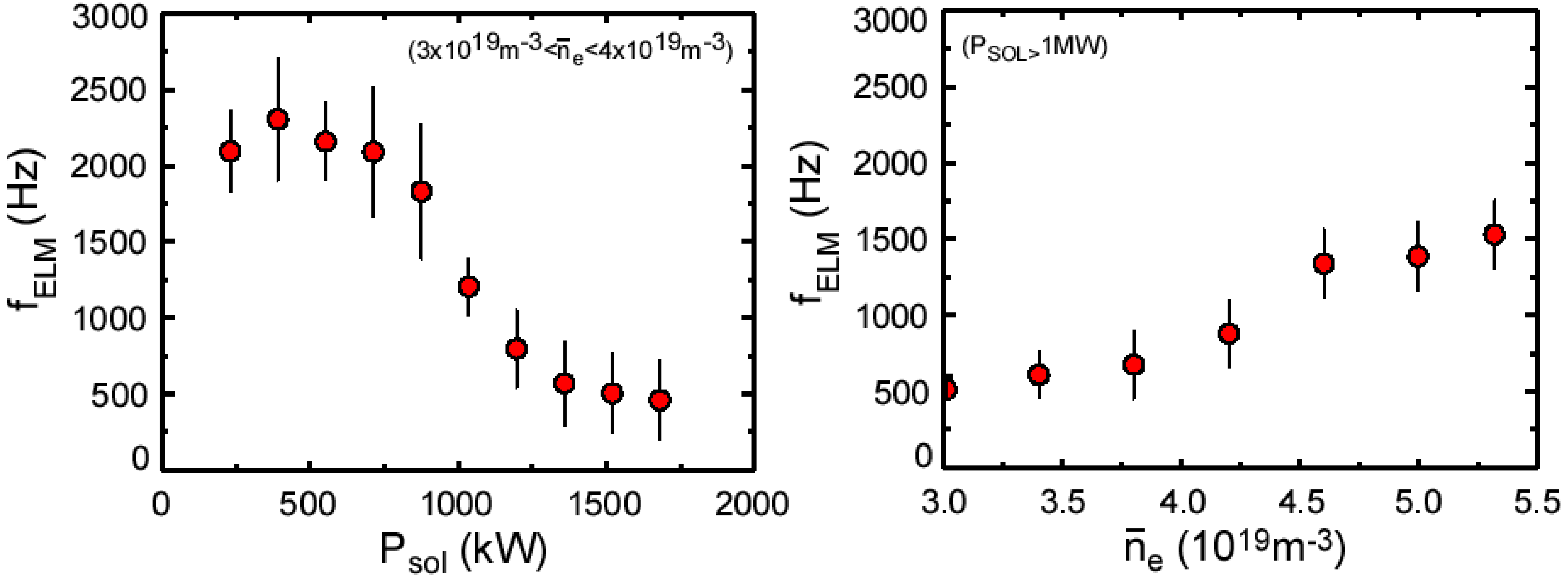


Strong correlation to pedestal density

Energy losses dominated by convection from the edge

ELMs show Type III characteristics



ELM frequency - falls with increasing P_{SOL}

- rises with increasing $\bar{n}_e$

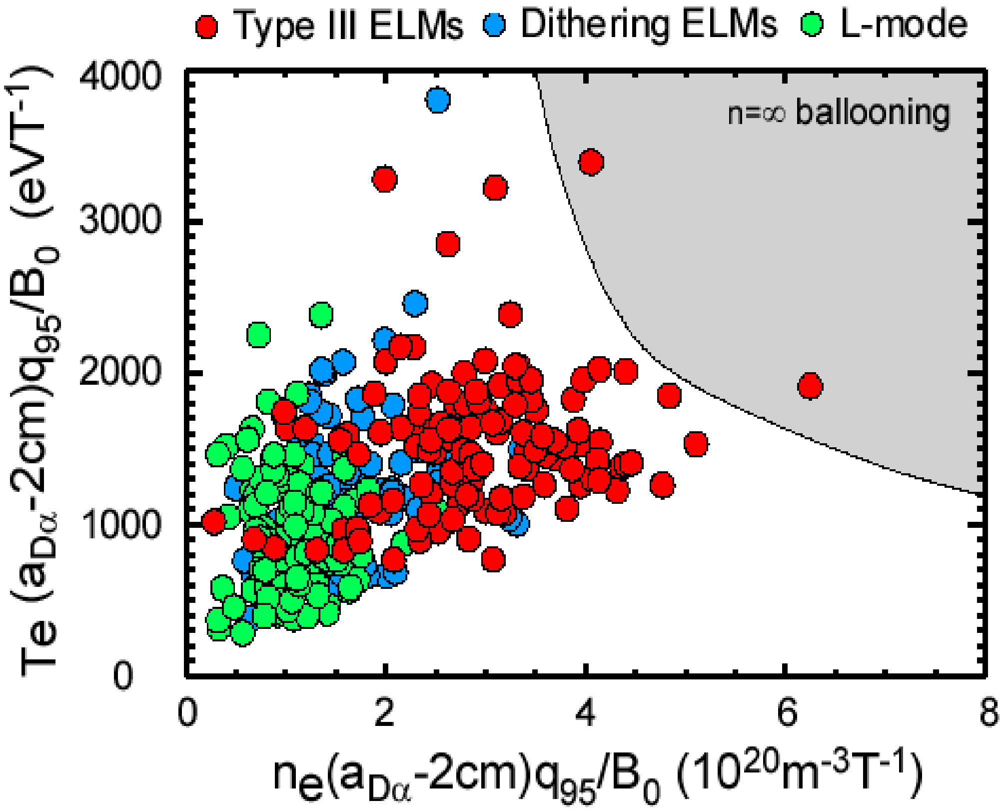
Consistent with Type III behaviour to maximum P_{SOL}

Stability analysis shows close to Type I ELMs

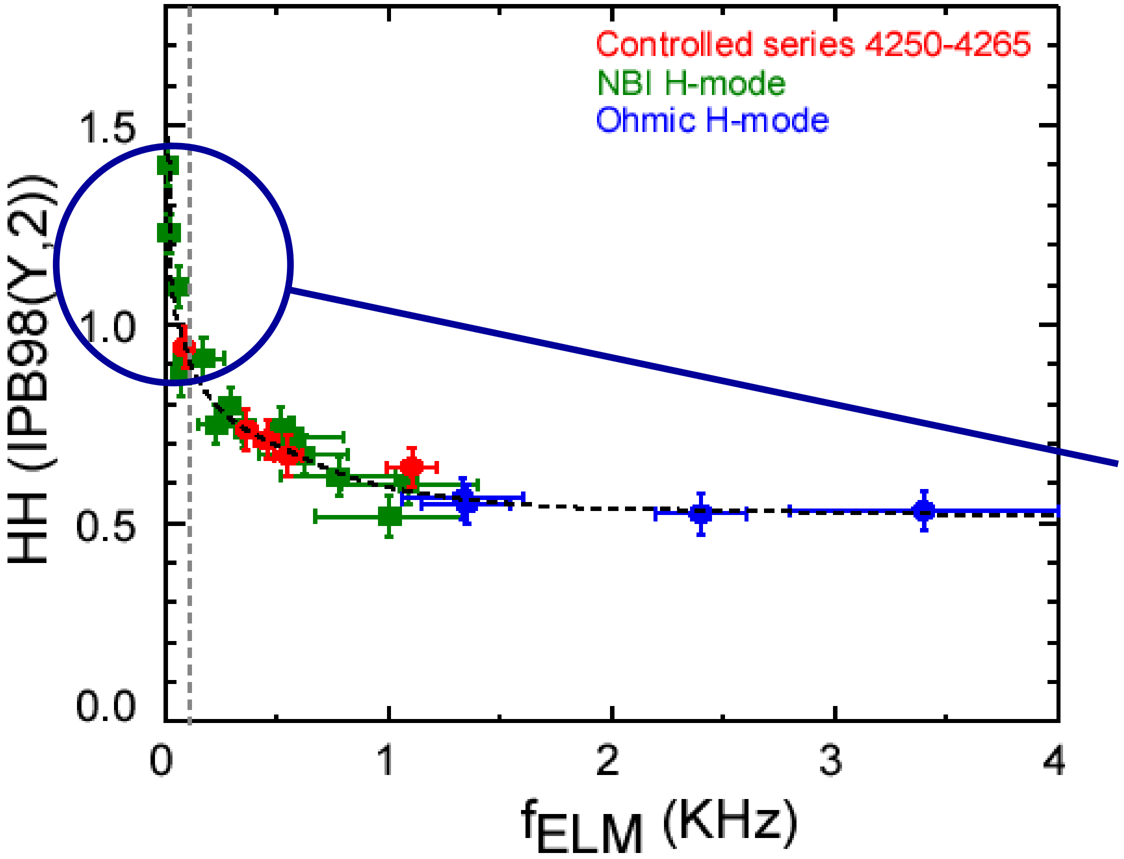
Type III ELMy behaviour confirmed in edge n-T space

Stability analysis shows ELMy H-modes lie in region of instability to peeling modes

Some ELMy H-modes close to ideal ballooning limit, where Type I ELMs might be expected



High Confinement with Type III ELMs



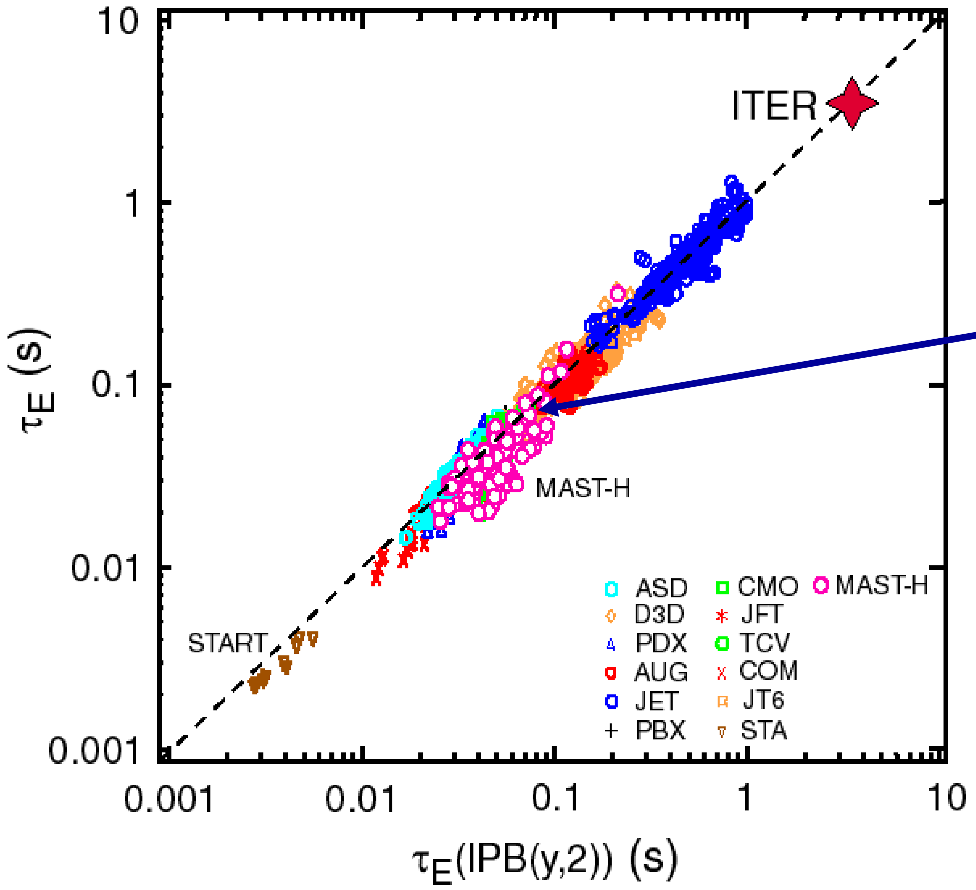
Benign Type III ELMs with high confinement

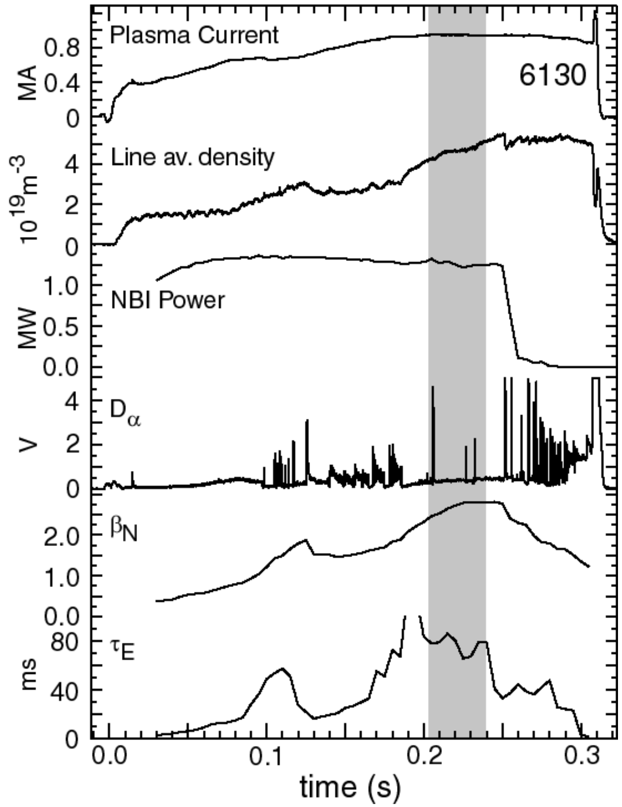
H_H (IPB(y,2))~1 or above for f_{ELM}<~100Hz

Global Confinement

Confinement data now suitable for International DB

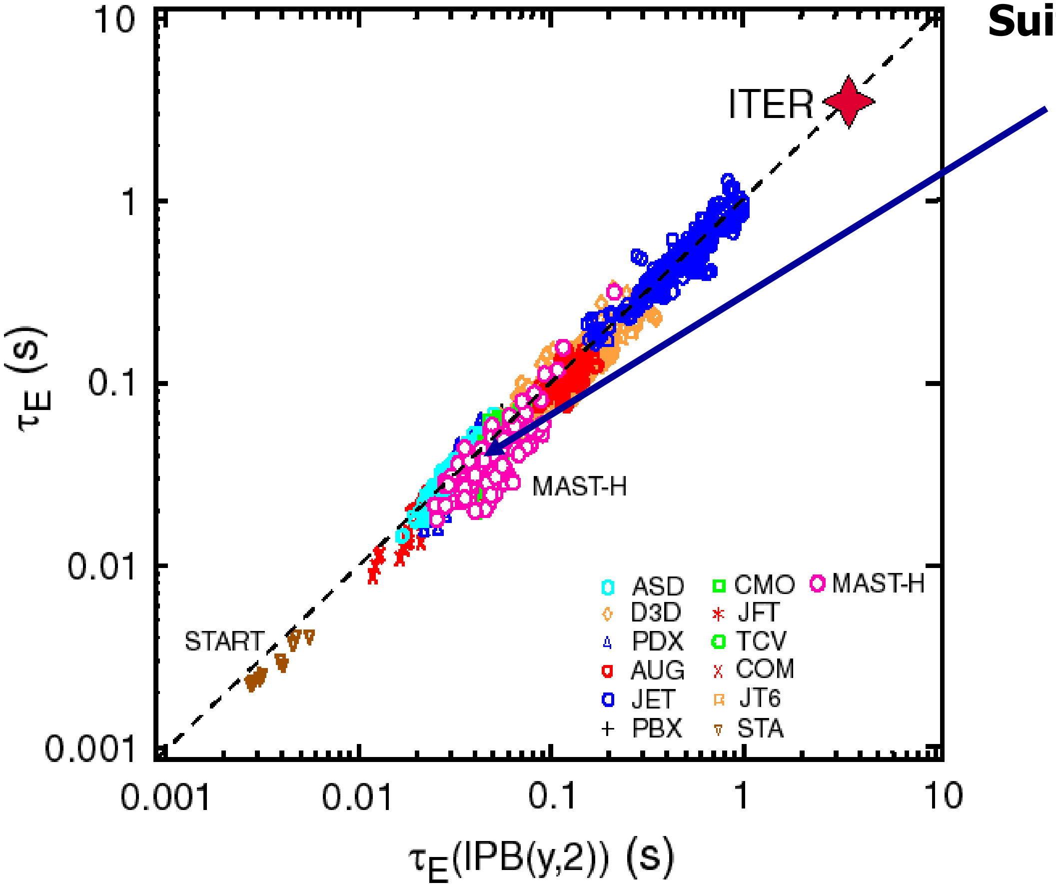
τ_E up to ~100ms typical in MAST ELMy H-mode

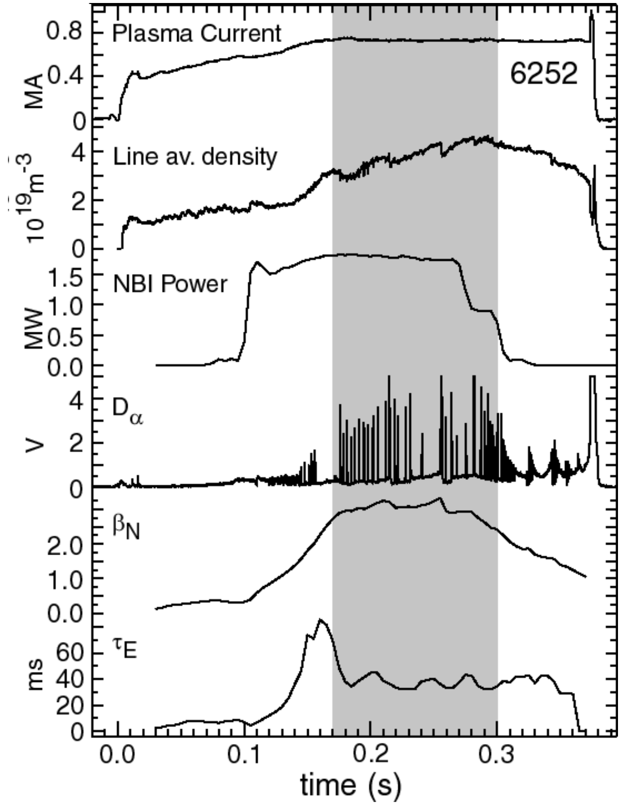




Confinement data now suitable for International DB

Quasi-stationary ELMy H-modes
Flat-top I_p, n_e b_N and τ_E maintained for $t>3\tau_E$
Suitable for submission to IDB



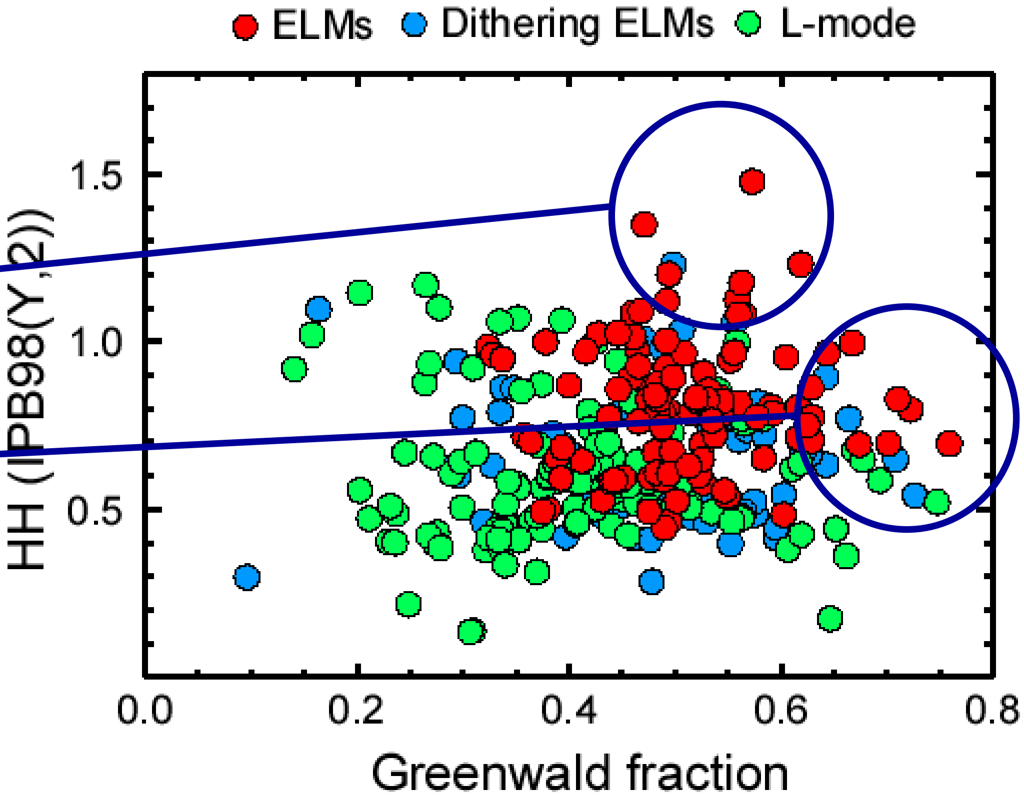


High Performance Plasmas

HH(IPB(y,2)) up to at least 1.5 in ELMy H-mode

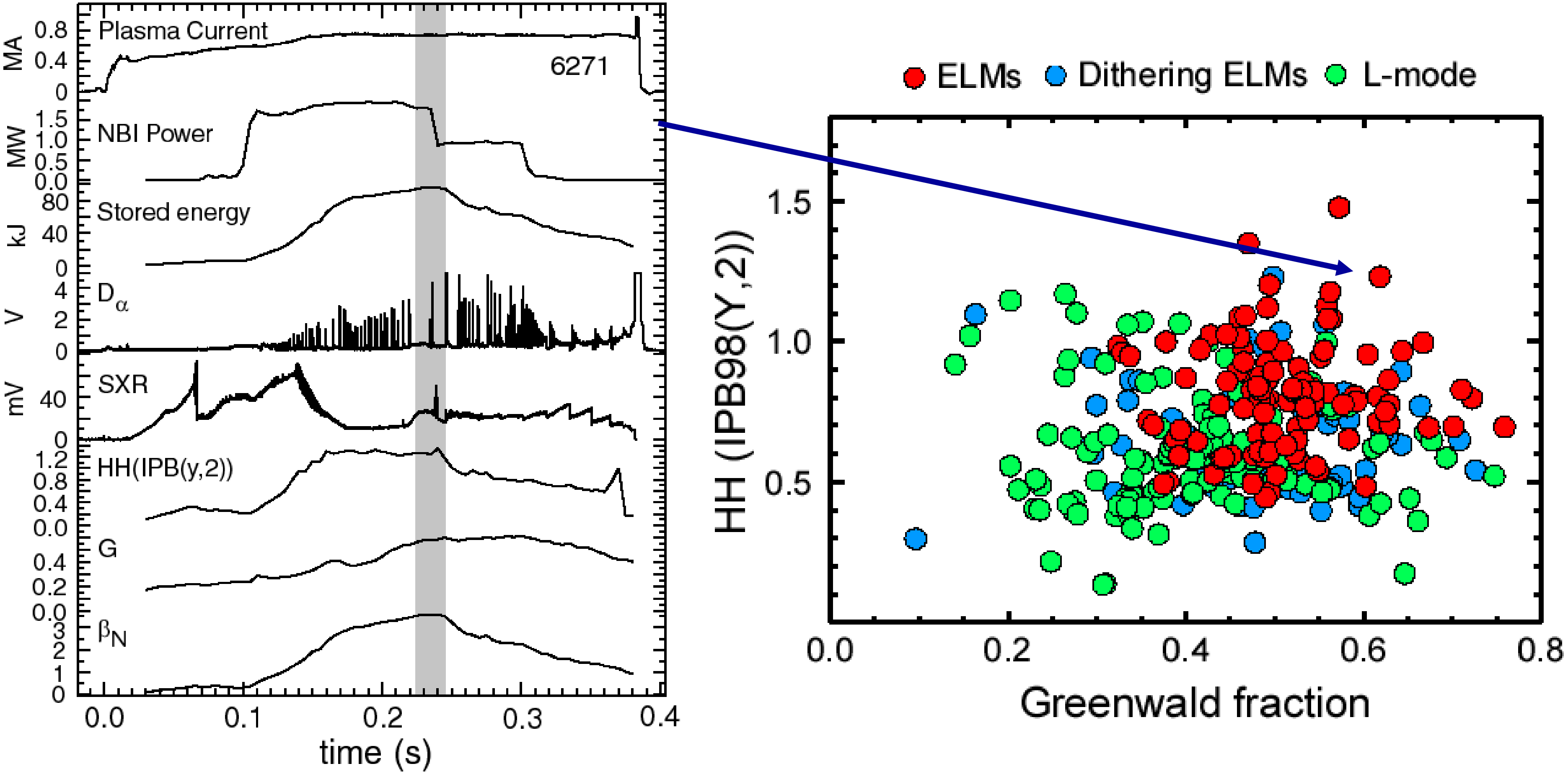
ELMy H-mode with G up to at least 0.8

- ITER relevent regimes, confirming value of MAST contribution to international databases



Simultaneous HH~1.2, G~0.6 and β_N~3.7 in ELMy H-mode - close to requirements for future, large DT ST device

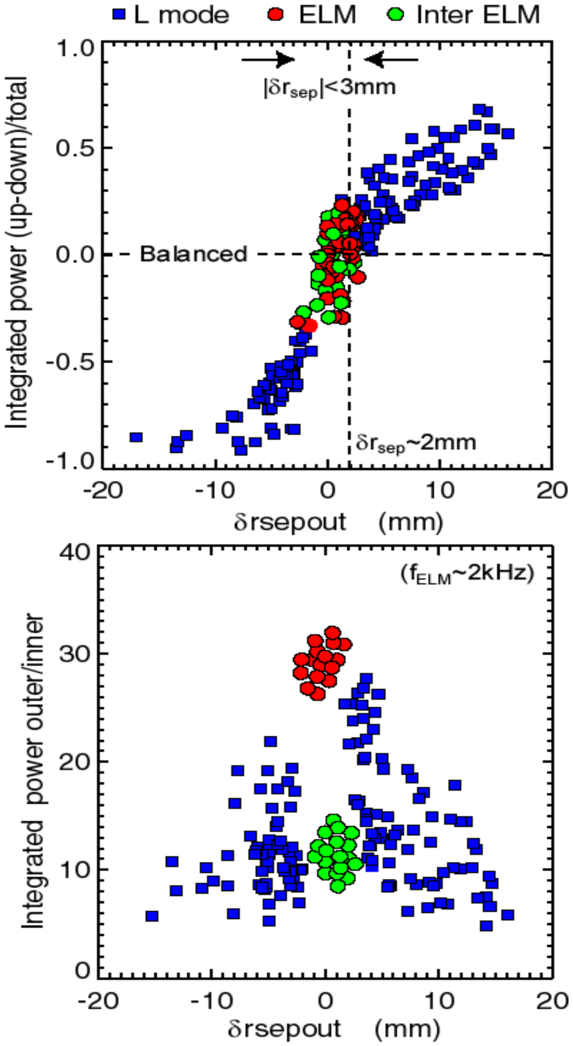
High Performance Plasmas



Simultaneous HH~1.2, G~0.6 and β_N~3.7 in ELMy H-mode - close to requirements for future, large DT ST device

Exhaust

Advantageous power distribution near CDN



H-mode access on MAST is easier close to CDN

Power losses, including those at ELMs are distributed -

- **symmetrically between upper and lower targets**
- **preferentially towards outboard targets (which have much larger wetted area)**

SOL Broadening by Divertor Biasing

Induce convective cells by divertor biasing:

Toroidally asymmetric biasing

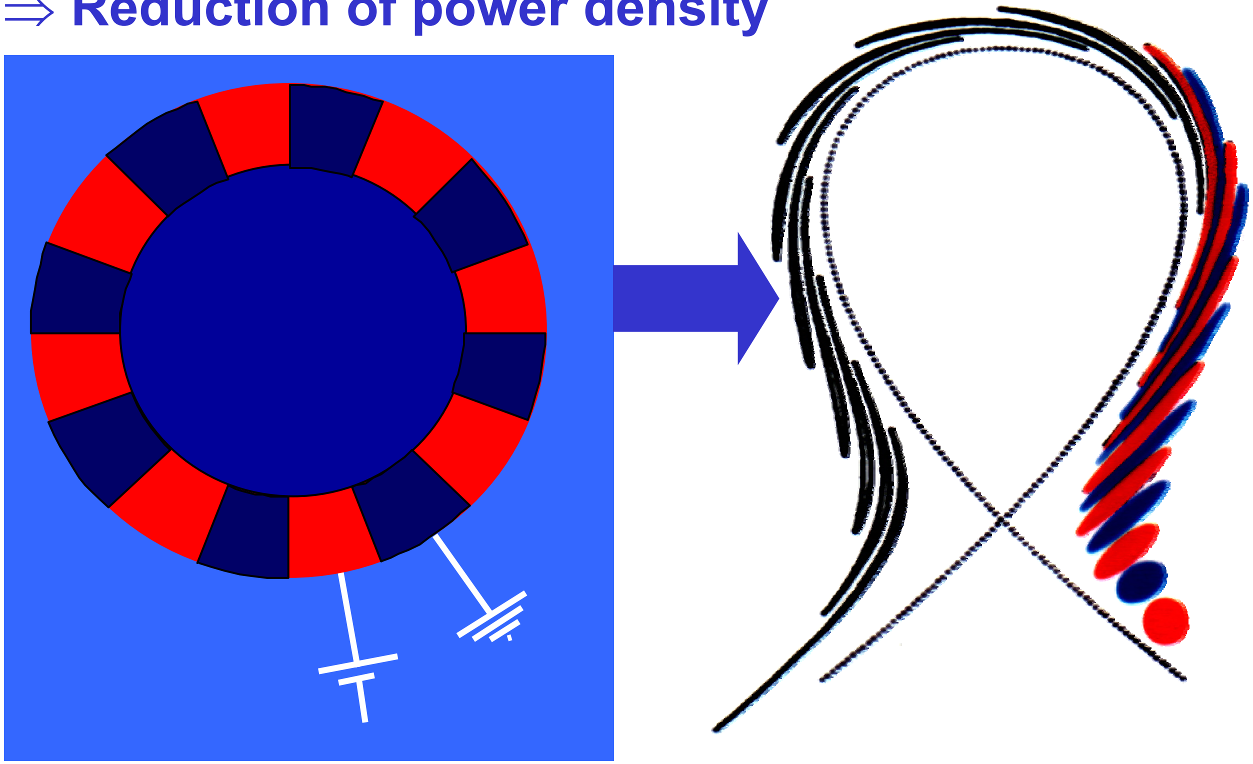
⇒ Potential variations in SOL

⇒ ExB driven convective cells

⇒ SOL broadening

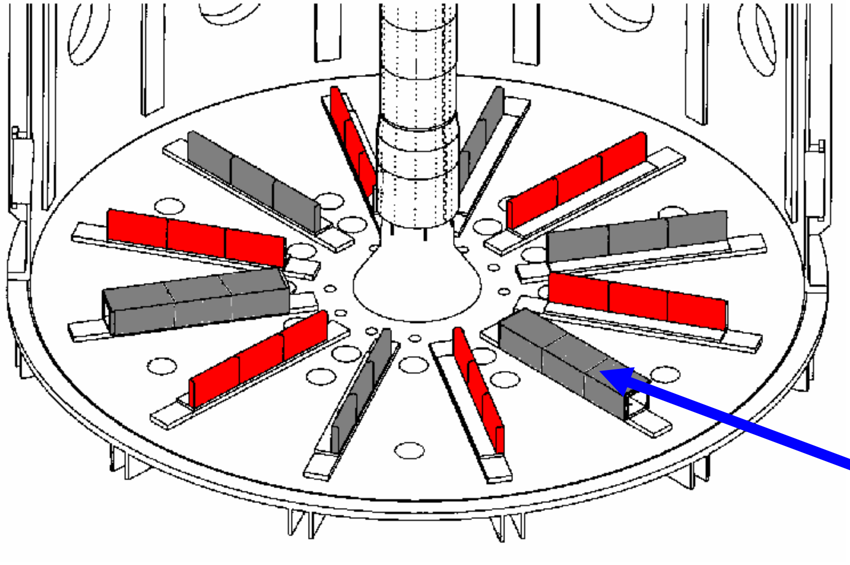
⇒ **Reduction of power density**

Areas of different potential generate convection cells driven by the ExB drift.

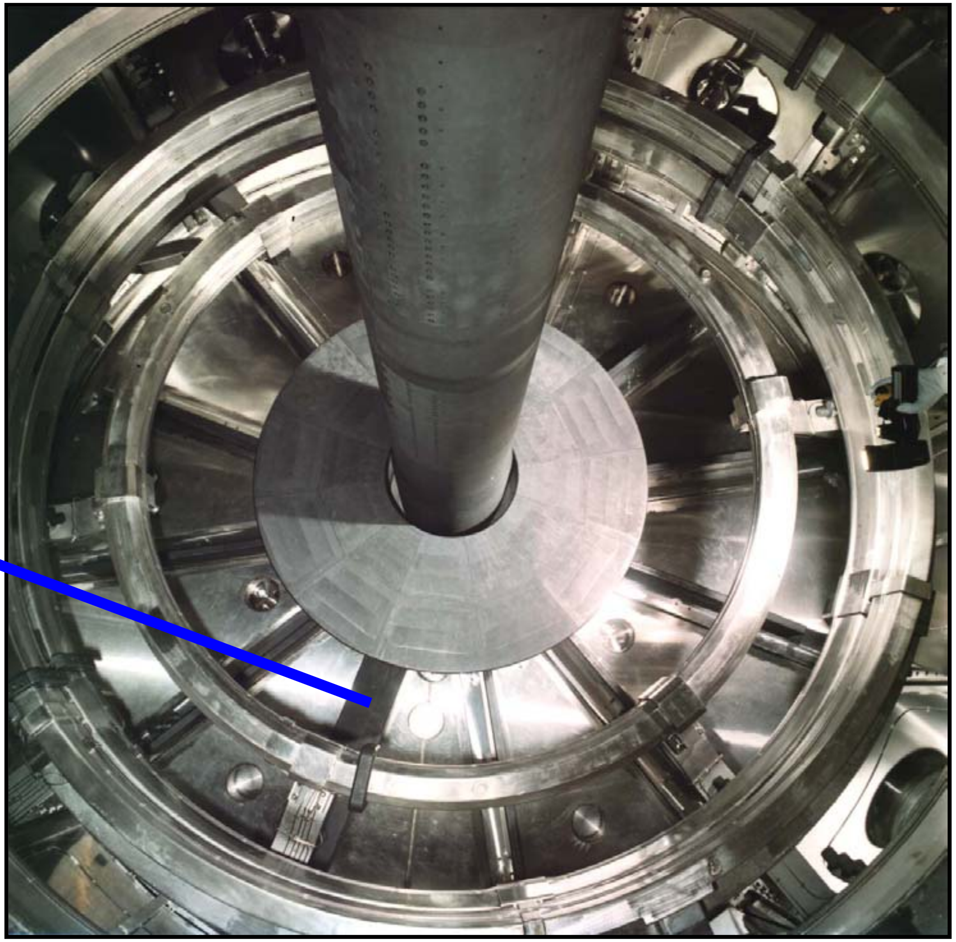


Applications to ITER using self-biasing of components (different materials, angled tiles etc.)

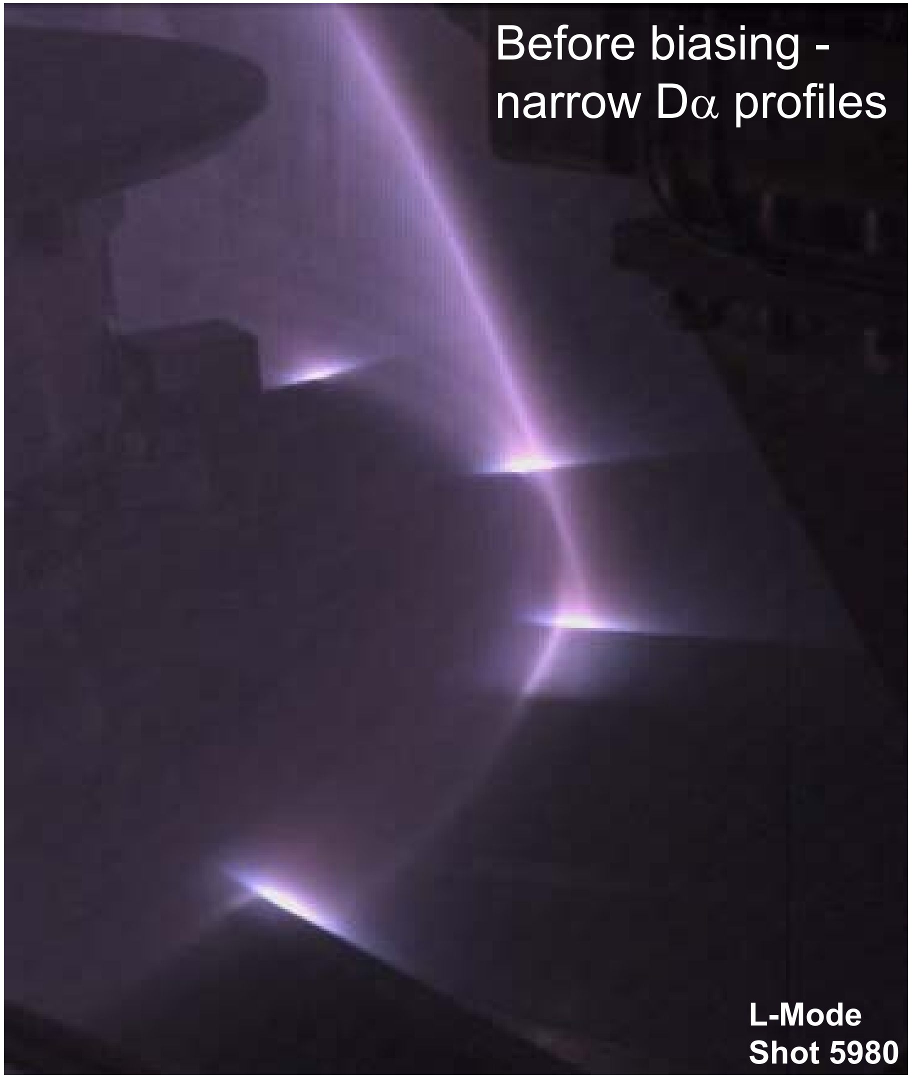
SOL Broadening by Divertor Biasing



Schematic of lower outer divertor region showing location of biased divertor ribs

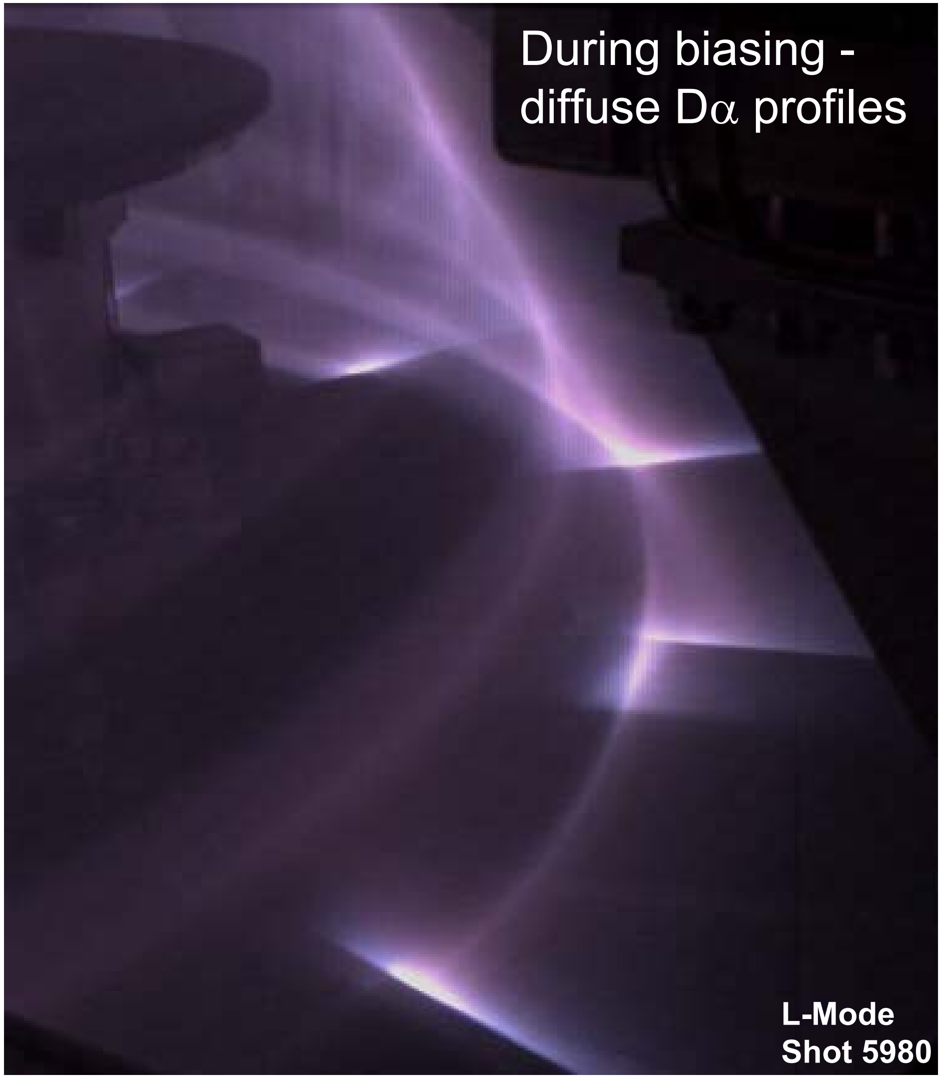


SOL Broadening by Divertor Biasing



Before biasing - narrow Dα profiles

L-Mode
Shot 5980

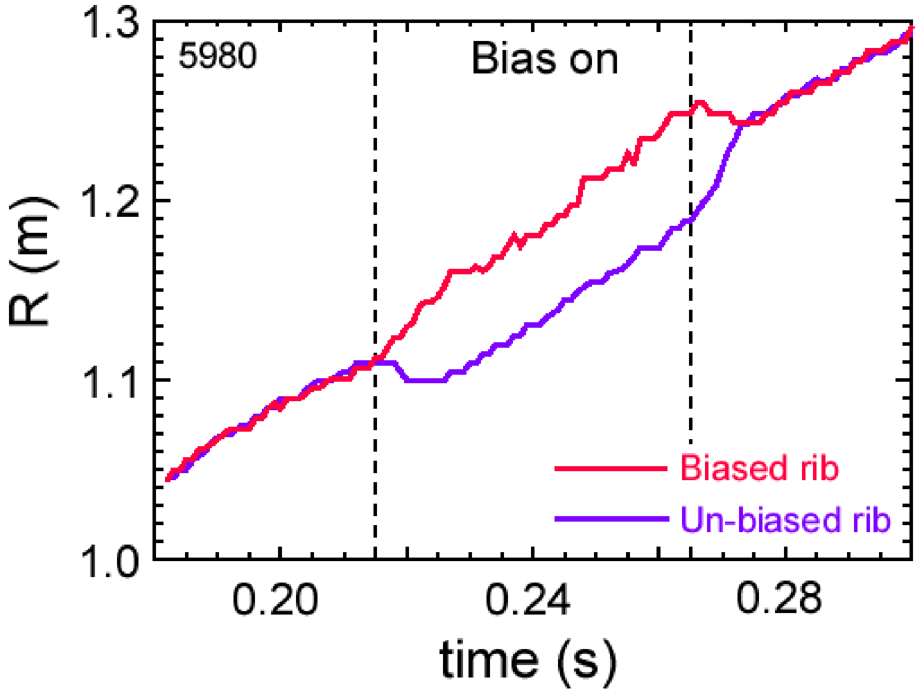


During biasing - diffuse Dα profiles

L-Mode
Shot 5980

SOL Broadening by Divertor Biasing

Biasing causes strike-point movement



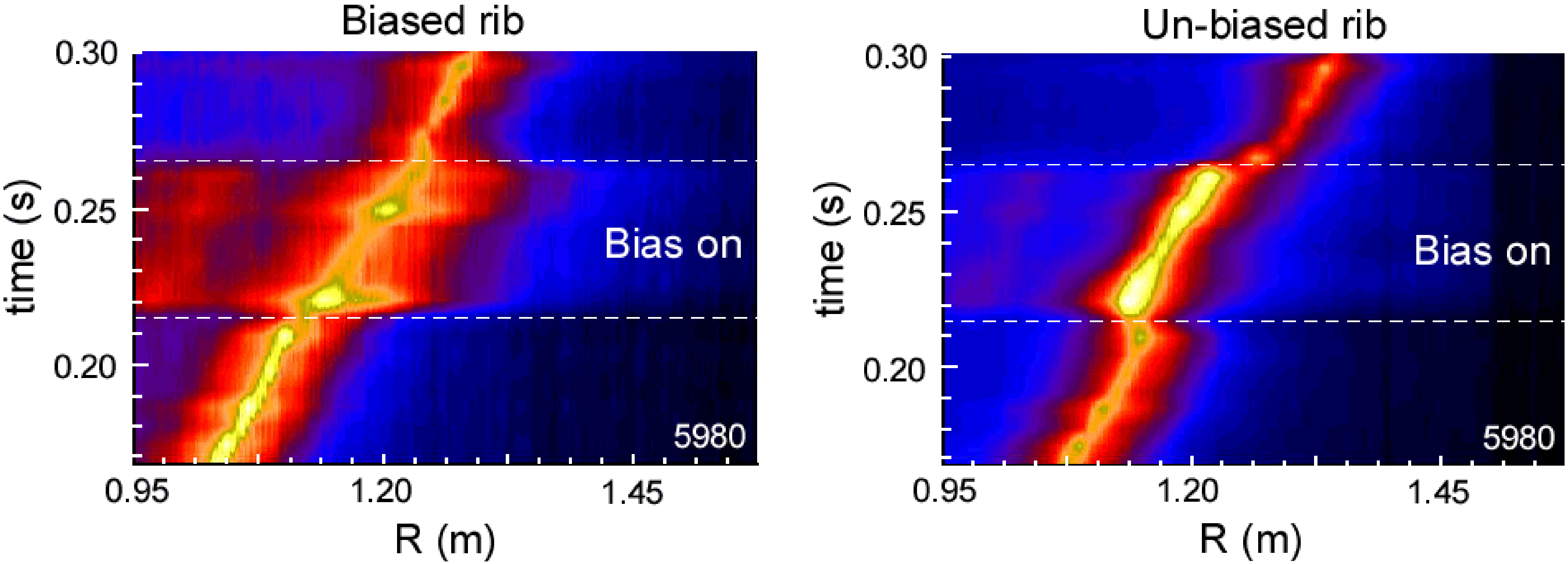
Motion of peak D_α emission on biased and un-biased ribs. Natural sweeping of strike points from solenoid fringing field

- Strike points on biased ribs move outwards by ~3cm

- On un-biased ribs, strike-points move in opposite direction (inwards)

- Result of ExB drift, shows electric field from biasing penetrates along SOL flux tubes

SOL Broadening by Divertor Biasing

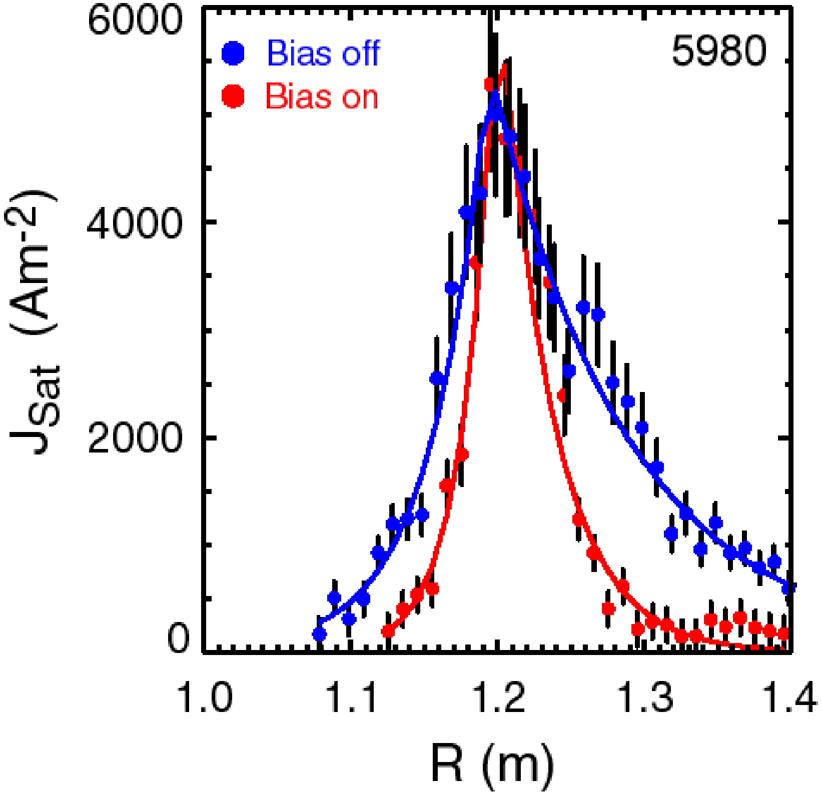


$\lambda_{D\alpha}$ on biased rib broadens by ~2.3, I_{peak} falls by 30%. On un-biased rib, $\lambda_{D\alpha}$ narrows by 40% and I_{peak} rises by factor 1.4

No significant changes to other 3 strike points or core plasma, consistent with theory

J_{sat} profile narrows on un-biased rib

- Peak j_{sat} little changed on un-biased rib
- λ_{jsat} narrows by factor ~2
- Total power to un-biased rib falls by >25%, despite rise in D_{α} intensity
- ‘Missing’ power and particles probably flow to biased ribs.
- Hoped to resolve issue with new, fast IR camera

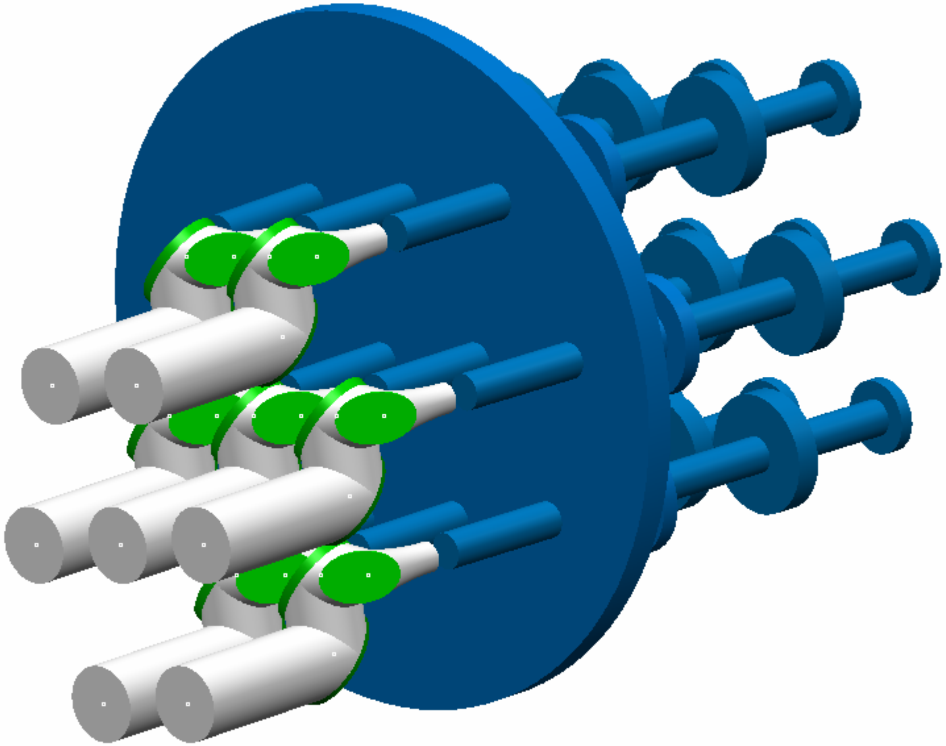


J_{sat} profiles across un-biased rib with biasing on and off (strike point positions adjusted)

Future Machine Upgrades

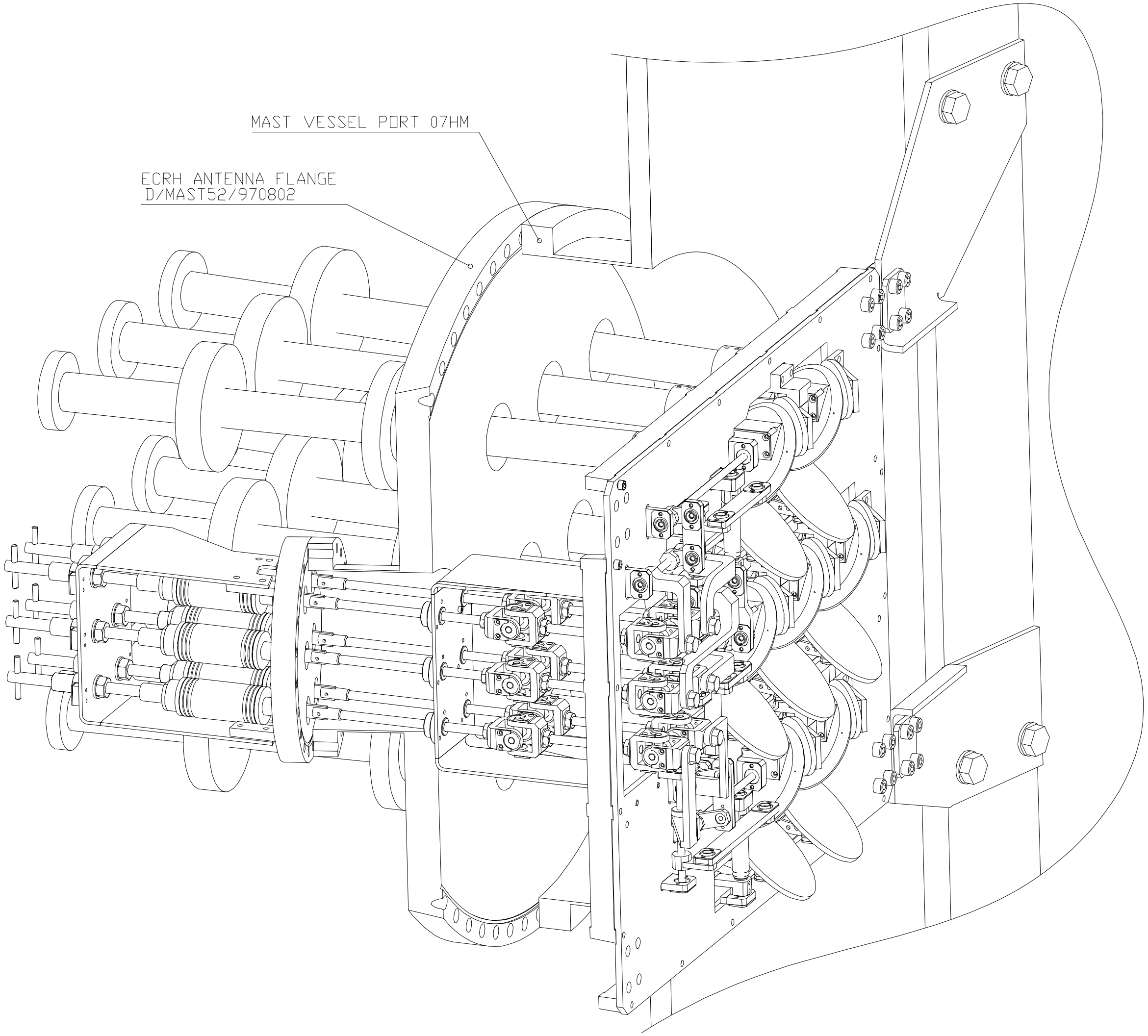
Plant Improvements

New centre column



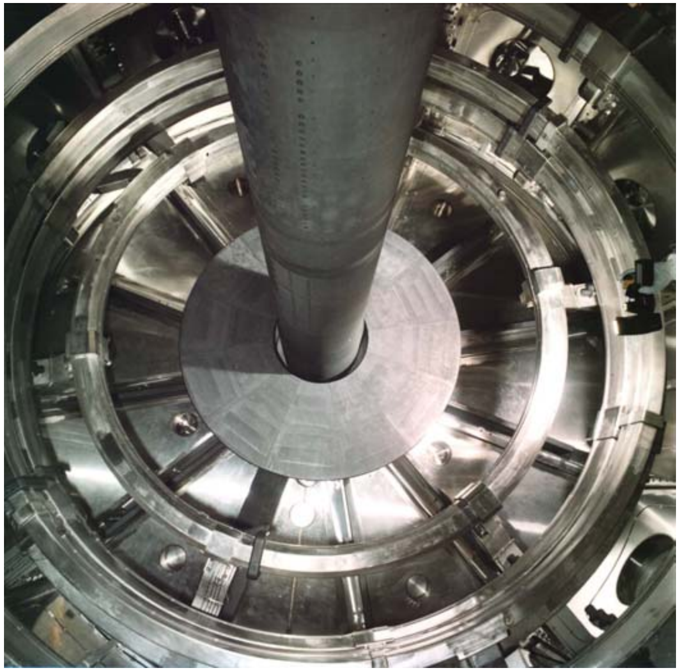
60GHz EBW Heating in MAST
(new antenna installation Sep 2002)

EBW Steerable Launcher

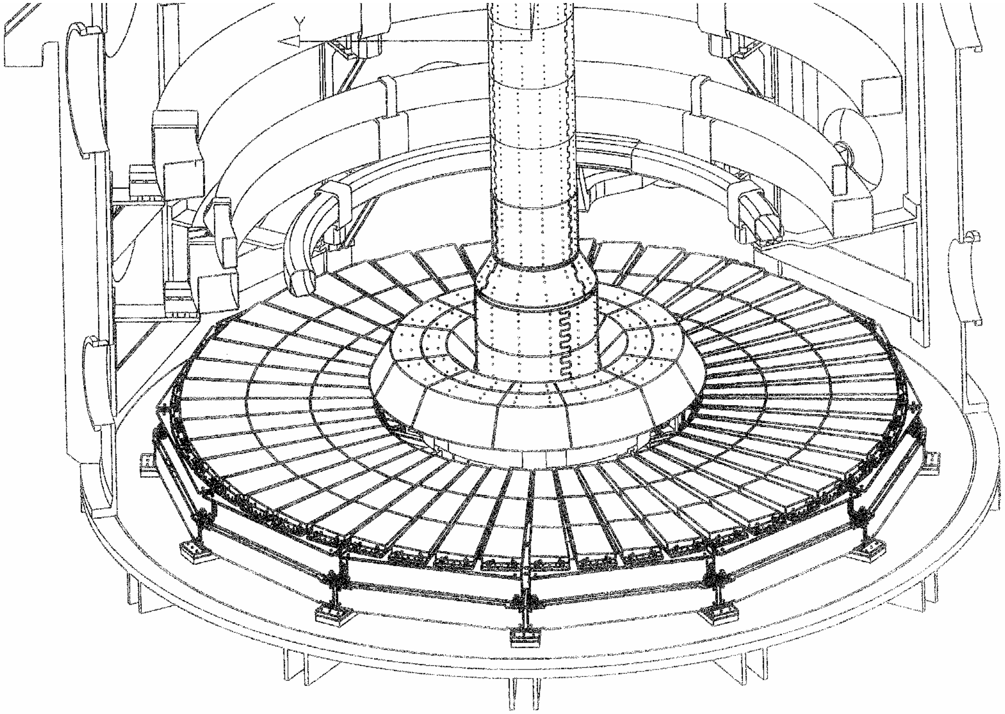


EBW Steerable Launcher

MAST Improved Divertor (MID)



Present divertor

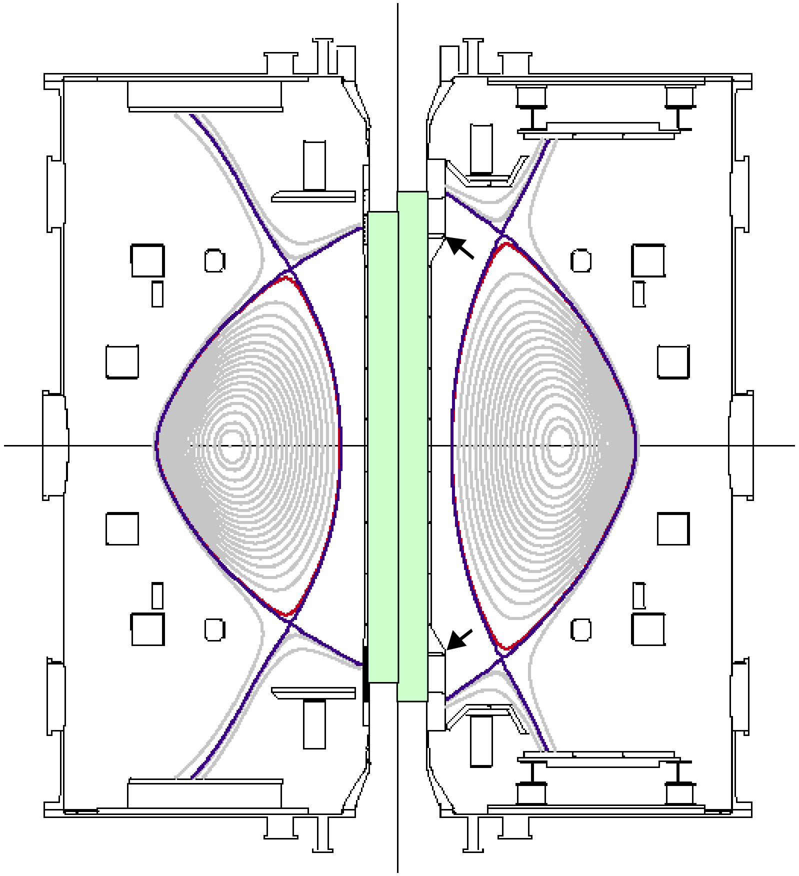


MID

MAST Improved Divertor (MID)

Design features:

- Controllable inboard gas-puff (arrowed)
- larger footprint for inner SOL strike points
- Smaler flat section of P2 armour, to ease H-mode access
- Longer solenoid and 10cm higher/lower P2 coils to aid high k



Work underway in collaboration with CRPP to increase baseline elongation

Current	k~2.5
Target	k~3.0

Forward Programme

2002 $P_{NBI} > 3MW$ & continuation of key ITER physics studies:

Sustained high beta operation (incl. NTM studies)
Increased elongation
Implement digital control system (this July)
Non-inductive current drive (NBCD, high bootstrap current regimes)
Confinement optimisation (energy/particle), H-mode dynamics
EBW tests
Divertor power loading studies (SOL scaling, detachment, divertor biasing)
and ELM characterisation/impact

Jan - Jun 2003

Install MAST improved divertor
Install new centre column - improved tails (-55-55kA swing rather than -40-40kA),
PF coil modifications + new graphite, designed for lower fringing field, higher κ etc.

2003 on - ITER studies + focus on key issues for development of ST concept

Extend pulse length to 5s, P_{NBI} to 5MW exploiting improved power handling capabilities
(SF6 in switch tubes for high voltage ops, improvements to the crowbar stack, restrike facility)
Exploit strong shaping capabilities of the ST ($\kappa \rightarrow 3$)
Innovative start-up/heating/current drive schemes (e.g. EBW)
Integrated scenarios (sustained high beta with high bootstrap fraction, NBCD, optimised
fuelling and effective exhaust)