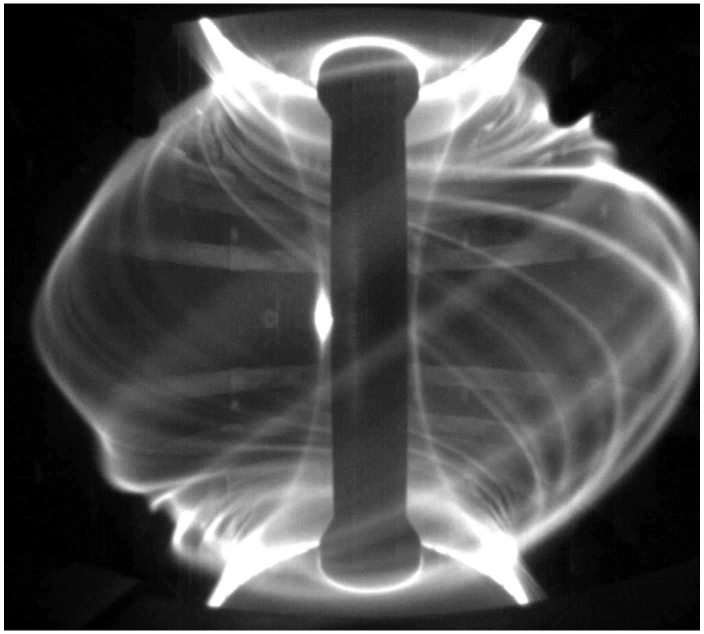
MAST Status & Plans



Brian Lloyd

EURATOM/UKAEA Fusion Association
Culham Science Centre, Abingdon, UK

PPPL 24th January 2008

UKAEA Fusion Working in Europe

MAST forward schedule

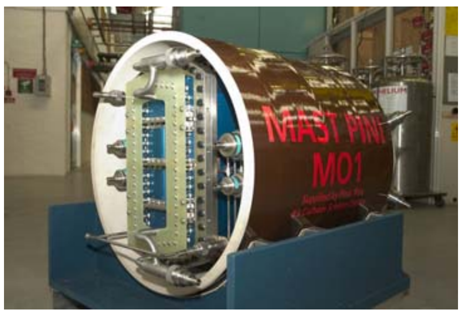
- Operations
- Engineering
- Restart

2008

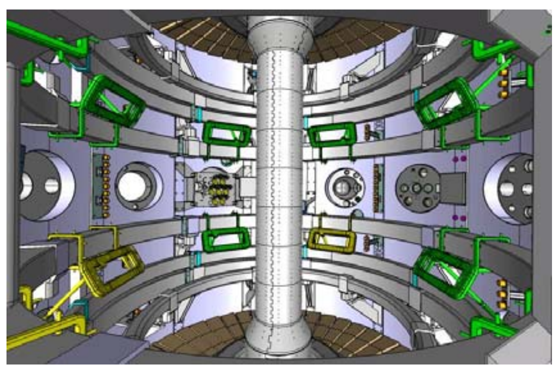
July | Feb | Apr | Nov

ELM coils
2^{nd} PINI
Multi-chord (>30) MSE
TS upgrade Phase I
(4 ⇒ 8 Nd:Yag lasers)

TS upgrade Phase II
(19 ⇒ 120 core channels)
BES 2D turbulence imaging



MAST PINI



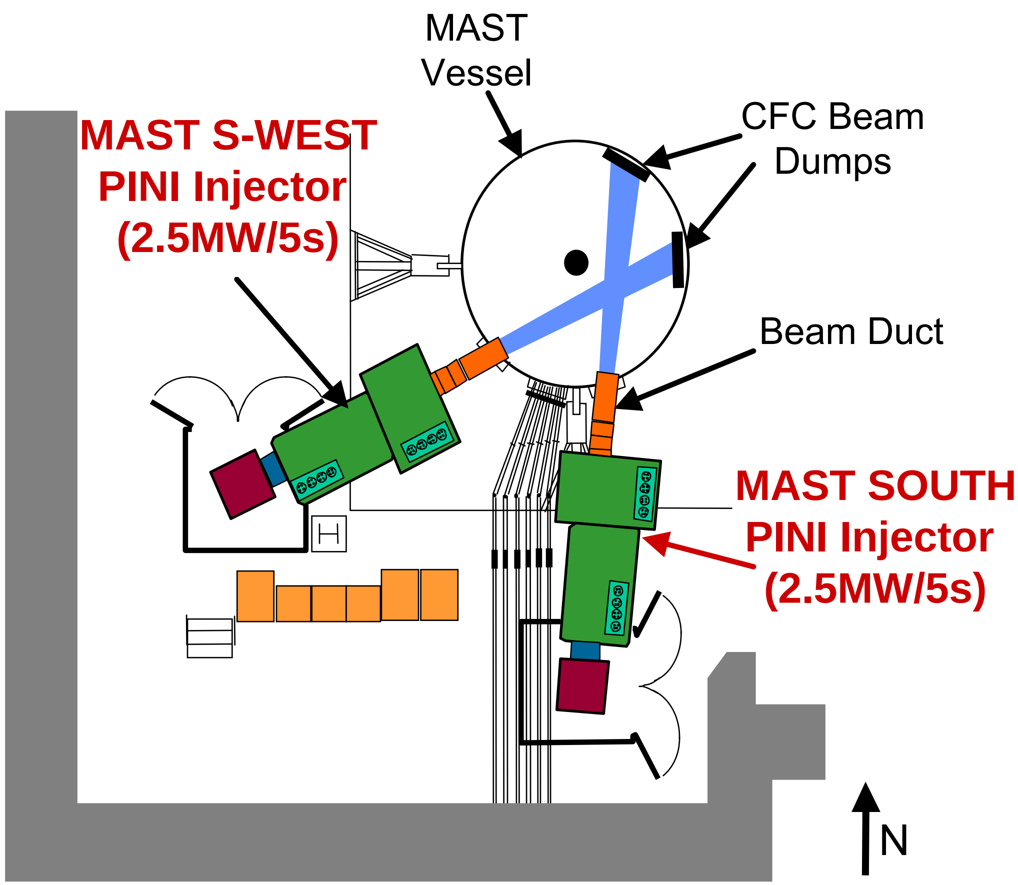
ELM/TAE coils
- control of edge instabilities
- controlled excitation of fast particle driven instabilities

BES turbulence imaging

UKAEA Fusion
Working in Europe

MAST control room re-furbishment

MAST NBI development

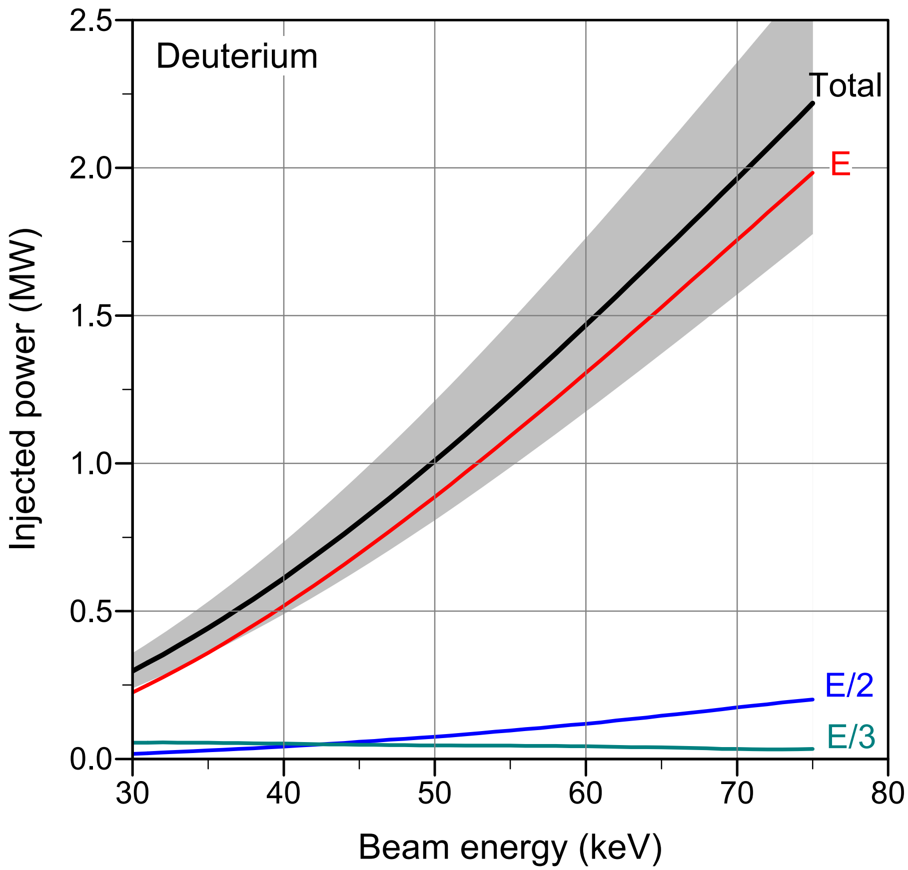


The original short pulse injectors obtained on loan from ORNL have now both been replaced by long pulse JET style PINIs

The S-injector was used in the 2007 campaign, operating reliably at high power and with highly reproducible beam parameters.

The SW-injector will now also be available for the 2008 campaign.

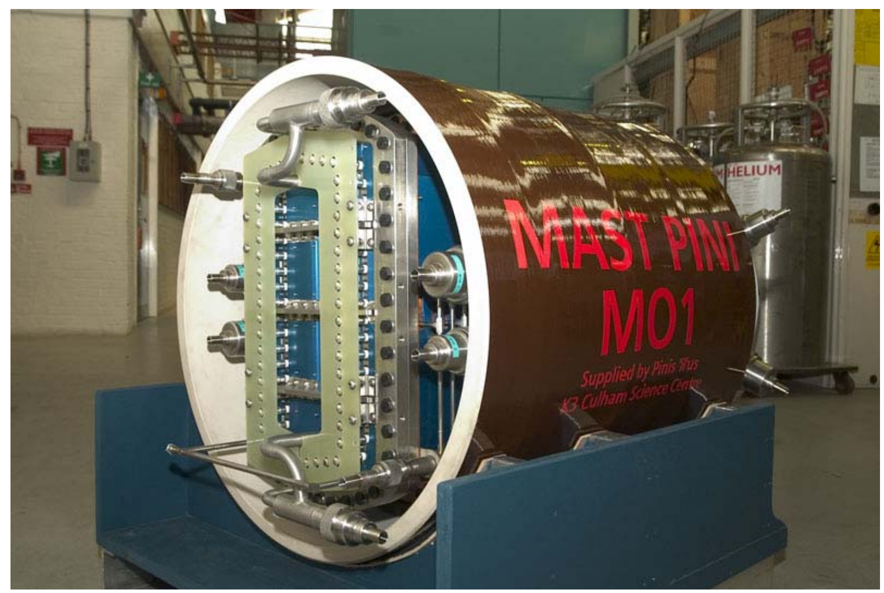
MAST PINI parameters



Injected power dependence on beam energy – deuterium beam at optimum perveance. Shaded area corresponds to ±20% power variation at fixed beam energy.

Design parameters of the MAST PINI (deuterium beam):

Maximum pulse length:	**5 s**
Maximum beam voltage:	**75 kV**
Maximum beam current:	**65 A**
Optimum perveance:	**2.9 μA/V$^{3/2}$**
	(75kV/60A ⇔ 2.2 MW)
Maximum injected power:	**2.5 MW**
	(75kV/65A ⇔ 3.2 μA/V$^{3/2}$)



Other technical developments – 2006/07

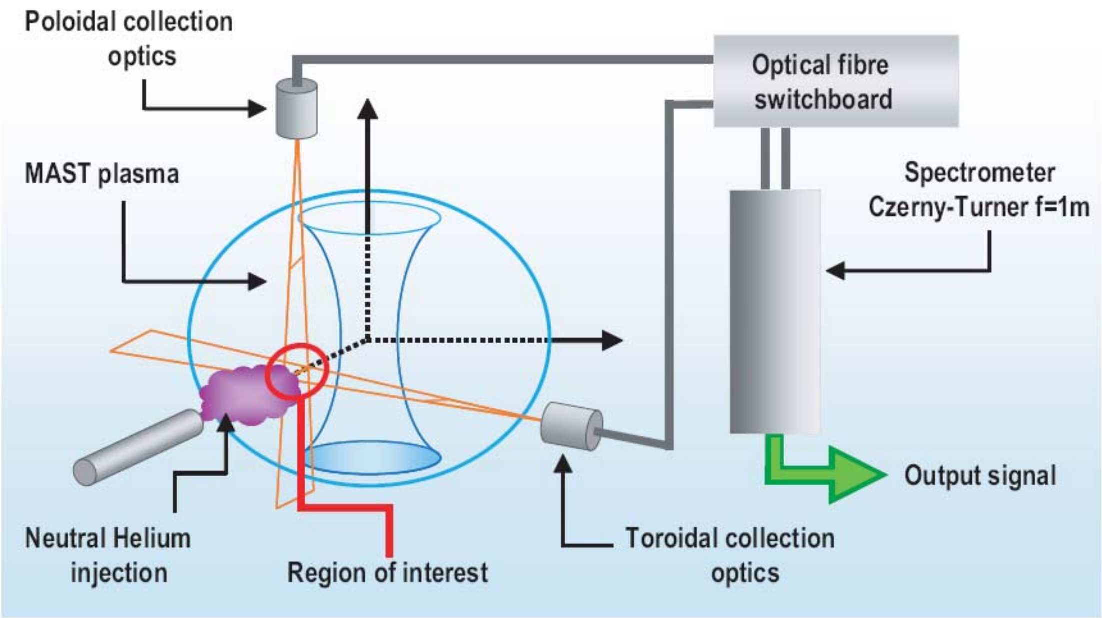
2006

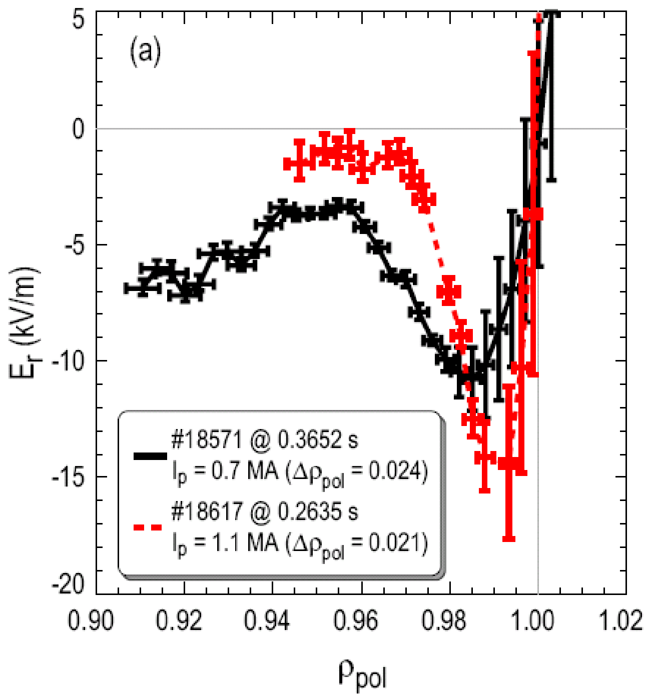
- First deployment of real time equilibrium construction in digital control system – based on RTEFIT and PCS (General Atomics)
- High resolution CXRS system
- High resolution edge TS system (in collaboration with Cork Univ.)
- Prototype MSE system (in collaboration with VR Sweden)

2007

- First data from prototype TAE coils
- Prototype BES fluctuation system (in collaboration with HAS Hungary)
- High resolution edge Doppler spectroscopy system
- EBW radiometer with fast spinning mirror
- Commissioning and exploitation of 28GHz, 150kW EBW start-up system
- First data from compact NPA (in collaboration with IPP Greifswald)

Edge Doppler spectroscopy





- ❑ Up to 120 lines of sight
- ❑ Arbitrary choice from 64 poloidal, 64 toroidal, 1 radial and 1 spectral lamp chords

$$E_r \approx \frac{\nabla p_\alpha}{eZ_\alpha n_\alpha} + v_{\alpha,\phi}B_\theta - v_{\alpha,\theta}B_\phi + \cdots$$

- need to measure both velocity components at edge of MAST ($B_\theta \sim B_\phi$)

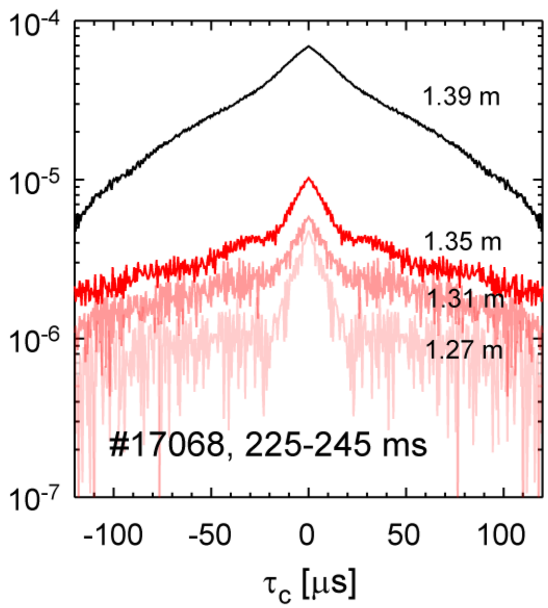
- ❑ Spatial resolution up to 1.5mm
- ❑ Temporal resolution up to 110μs (10 lines of sight)
- ❑ Absolute velocity from spectral lamp or radial chord

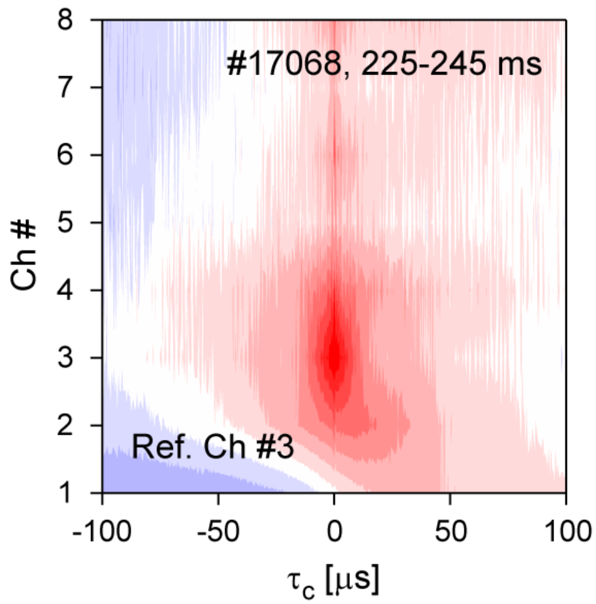
Trial BES fluctuation measurements

Collaboration with HAS, Hungary

- BES measures density fluctuations from D_α emission from excited atoms in heating beam
- 8 channel system shared optics with CXRS
- 1 MHz APD camera developed at RMKI

auto- and cross-correlations

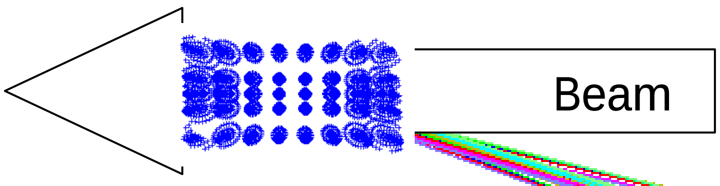


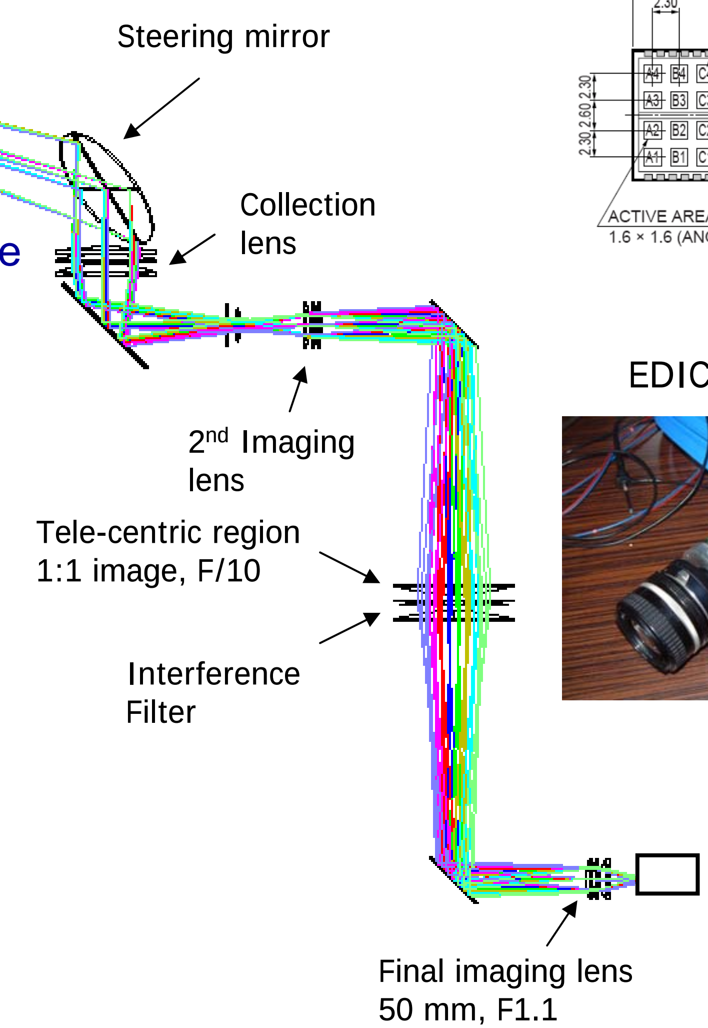


- Amplitude higher at edge than core
- Core correlation time τ_c ~ 10µs
- Longer timescale at edge τ_c < 100µs

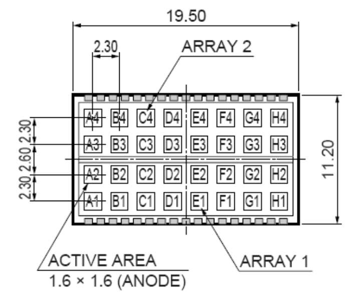
- Correlation length L_c ~ 4 cm
- Long range correlation due to beam density fluctuations

BES 2D turbulence imaging system





Hamamatsu S5880
8x4 APD array



EDICAM (RMKI)

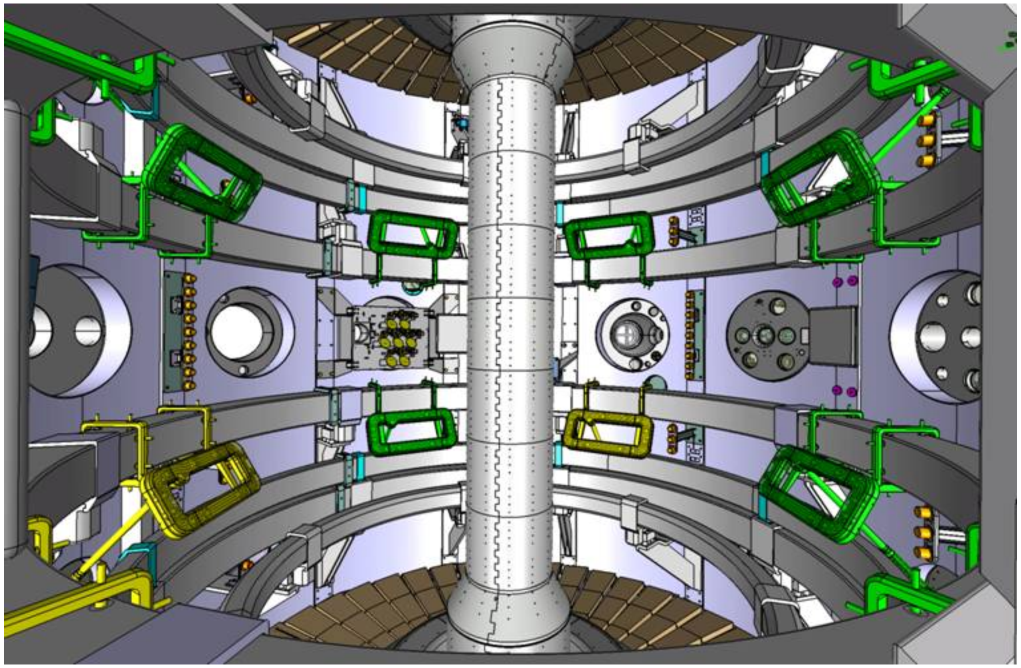
- 2D BES imaging for meso-scale turbulence
- $f < 1$ MHz, $k_{r,\theta} < 1.6$ cm^{-1}, $k_{\perp}\rho_i < 1$
- Custom 8x4 channel 1 MHz APD camera
- In-vessel optics, single interference filter
- Development and exploitation in collaboration with HAS-RMKI/KFKI Budapest
- Planned installation end 2008

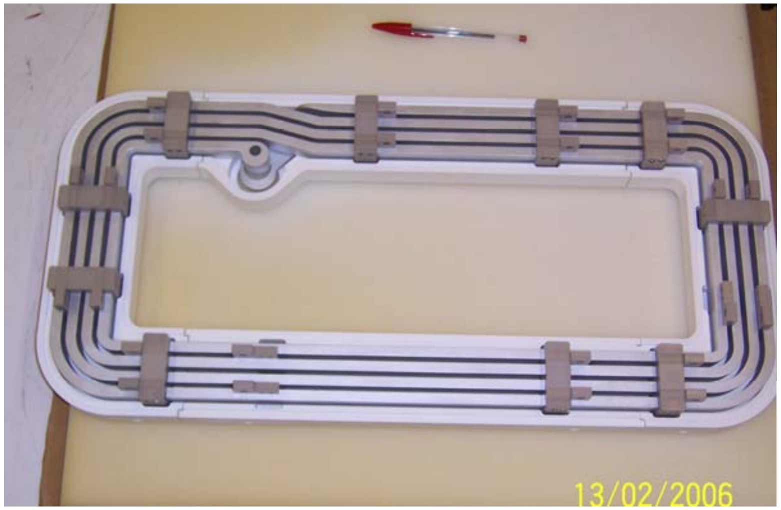
KFKI-RMKI

Technical developments – 2008/09

- Installation & commissioning of 2nd PINI source
- ELM (& TAE) 6 + 6 coil array (designed in collaboration with CEA, FZJ)
- Major developments to Nd:YAG Thomson scattering system - more lasers, better spatial resolution (in collaboration with York University)
- Multi-channel MSE installation (with VR Sweden, DCU Ireland)
- BES 2D turbulence imaging system (in collaboration with HAS Hungary)
- Divertor science facility
- Data acquisition system developments for long pulse operation
- Upgrade digital control to PC-based system (performance, expandability, longevity)
- New NBI HVPS (contract placement 2008)
- Higher power (350kW), long pulse 28GHz gyrotron (on loan from ORNL)
- Centre column chiller system (ready Dec 2008 – installation date t.b.d.)

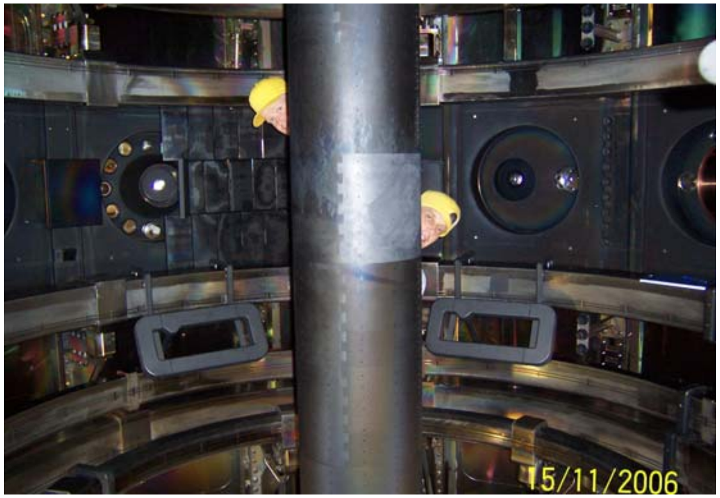
ELM control coils



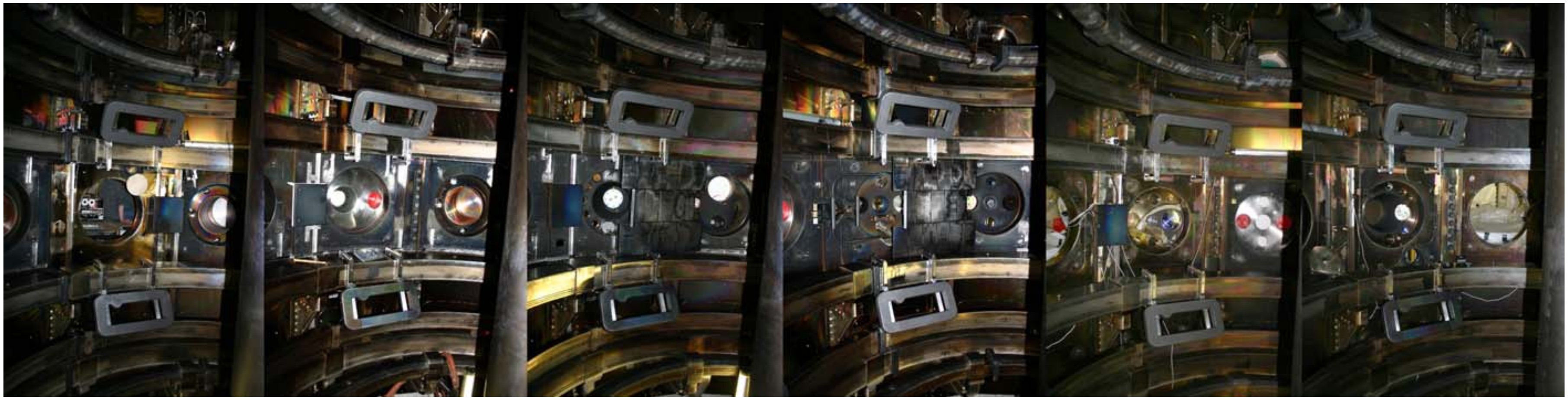


ELM control by ‘ergodisation’ of the plasma edge

Excitation of TAE instabilities for controlled damping rate studies - prototype 3-coil array tested in 2007



ELM coils installed in MAST



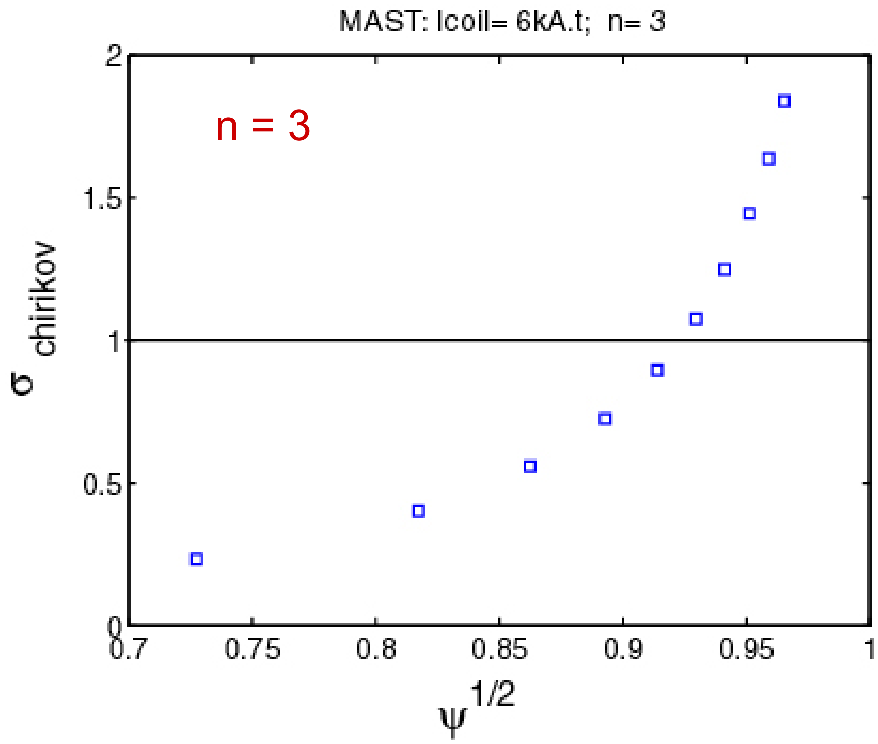
Predicted effect of the 12 coil system

In order to get an ergodised edge need the induced islands to overlap

Calculations show that unlike on DIII-D, due to the strong magnetic shear in an ST, the odd parity configuration is best

The degree of overlap is represented by the Chirikov parameter:

$$\sigma_{chir} = \frac{\delta_{mn} + \delta_{m+1,n}}{\Delta_{m,m+1}}$$



odd parity is resonant for q_{95}=4.9 (working equilibrium)

=> edge is ergodised, at $\psi^{1/2}$>0.92

Calculations have been performed by Marina Becoulet /CEA

ELM control coils

- It is not known whether ELM suppression is due to ergodisation or whether the island size relative to the pedestal width is the important factor.

- At 6kAt the edge perturbation is ~ same (b^r~2x10^{-4}T) as DIII-D and island width > pedestal width on MAST

- MAST experiments will hopefully give new insight

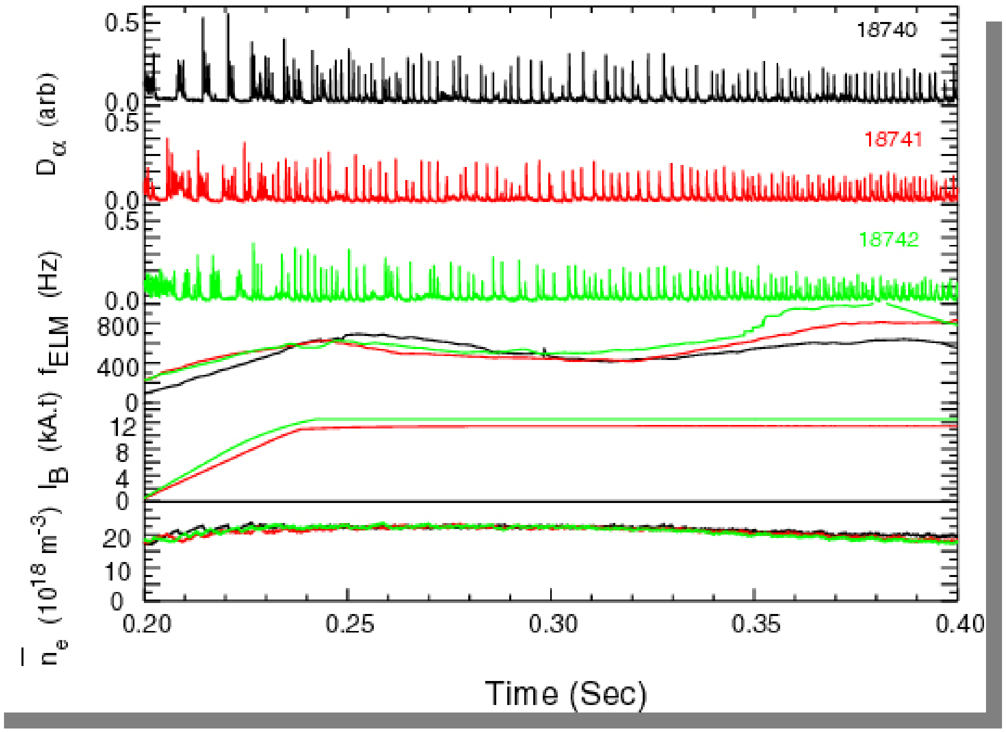
Tests on prototype 3-coil array:

  - Coils have been successfully powered up to 1kA in 2007

  - Voltage induced during disruptions < 20 V in a short spike that can be easily filtered

  - To date no significant power loads during discharge or disruptions

ELM mitigation with external EFCC



n=2 spectrum, I_{coil} up to 12kAt

$\sigma_{chirikov}$>1 to ψ_N~0.9 (Δ_{erg} ~ 0.1 ψ_N)

$\Delta_{erg}/\Delta_{ped}$ ~ 5

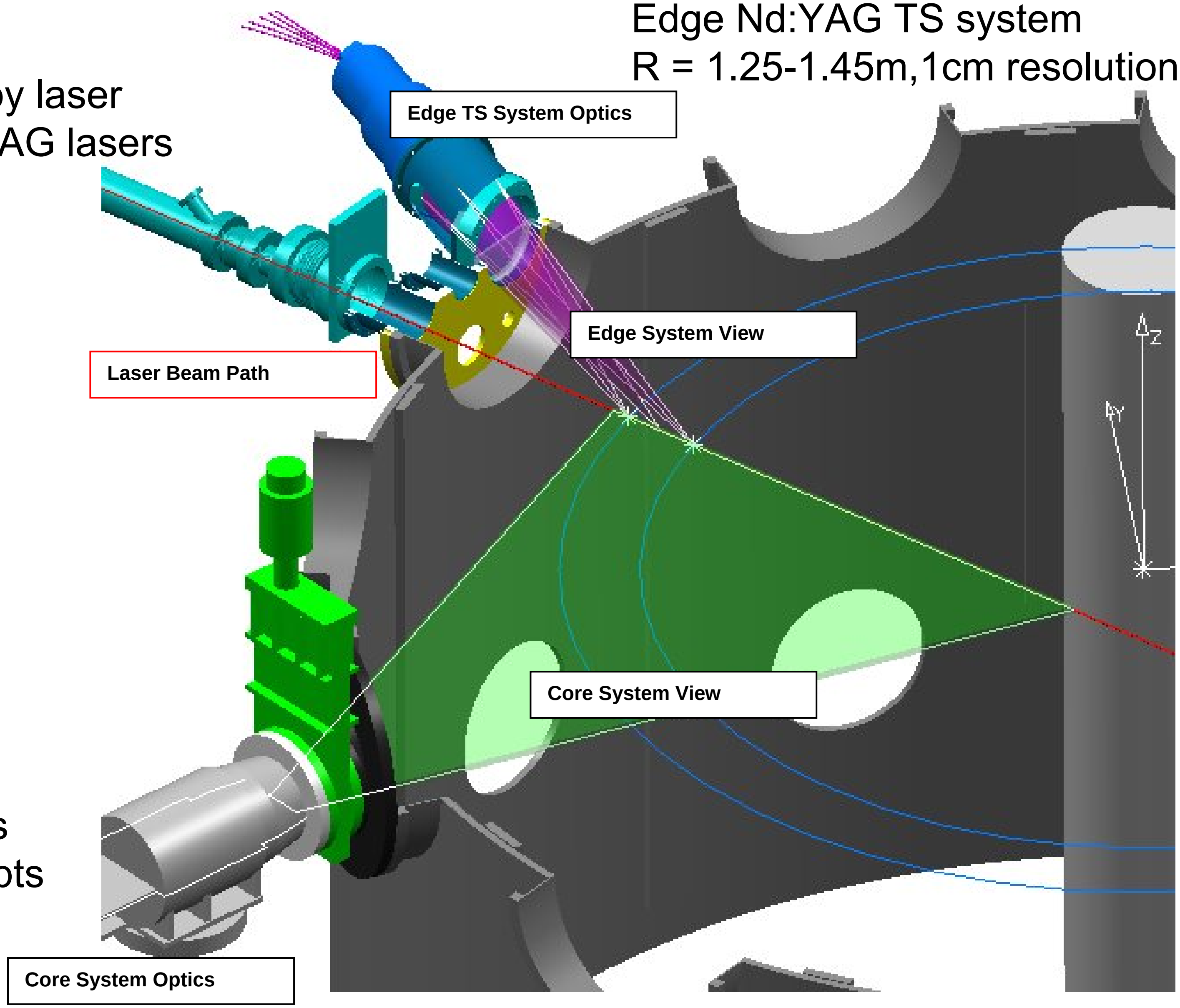
Δ_{island} ~ 1 cm ~ Δ_{ped}

- Clear effect but weak
- Low collisionality edge (but Type III ELMs..)
- No density pump-out

MAST Thomson scattering systems

Edge Nd:YAG TS system
R = 1.25-1.45m,1cm resolution

Single pulse 10J ruby laser
4 x 50Hz, 1.2J Nd:YAG lasers



Core ruby, 300 pts
Core Nd:YAG 19 pts

Nd:YAG TS upgrade

Collaboration with York University. To be fully implemented by 2009.

Technical specification

- 120 spatial points, ~10mm resolution, 240Hz
- F number halved, laser energy increased to 1.6J
- Number of lasers doubled to 8 (but each laser 30Hz vs 50Hz at present) enhancing burst mode capability for NTM, ELM studies etc.

Applications

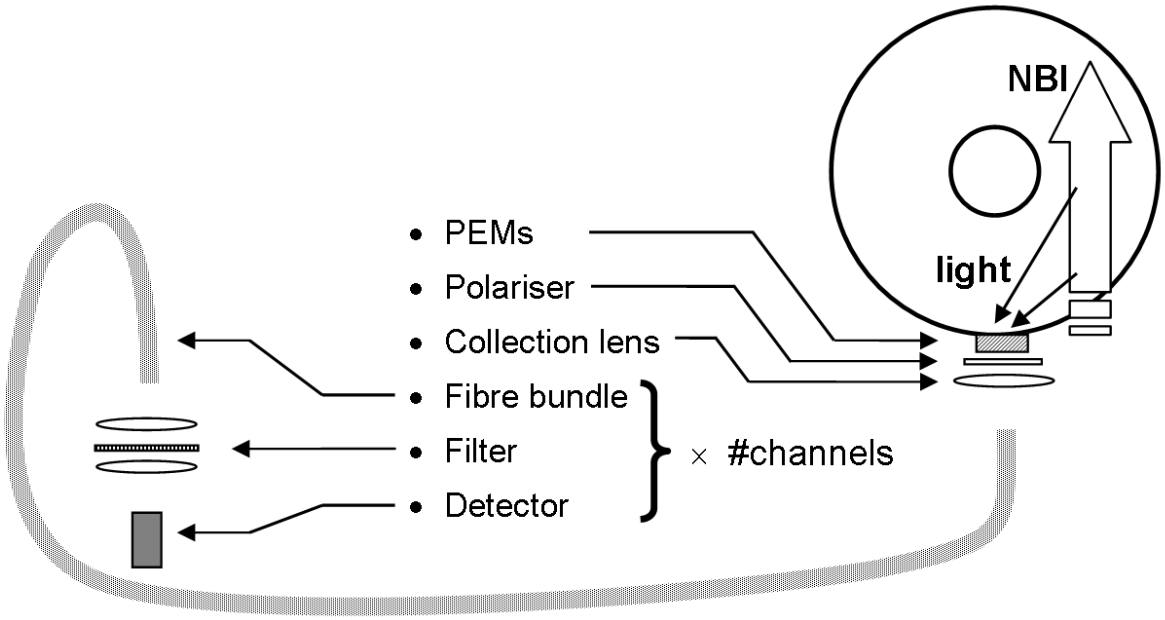
- Transport analysis (spatial resolution comparable to CXRS) including eITB evolution
- Transport in and around magnetic islands
- Pellet ablation and associated particle transport
- Transient events (e.g. ELMs and other filamentary structures)

Multi-chord MSE

Motional Stark effect (MSE) measurements challenging in the ST because of the low magnetic field

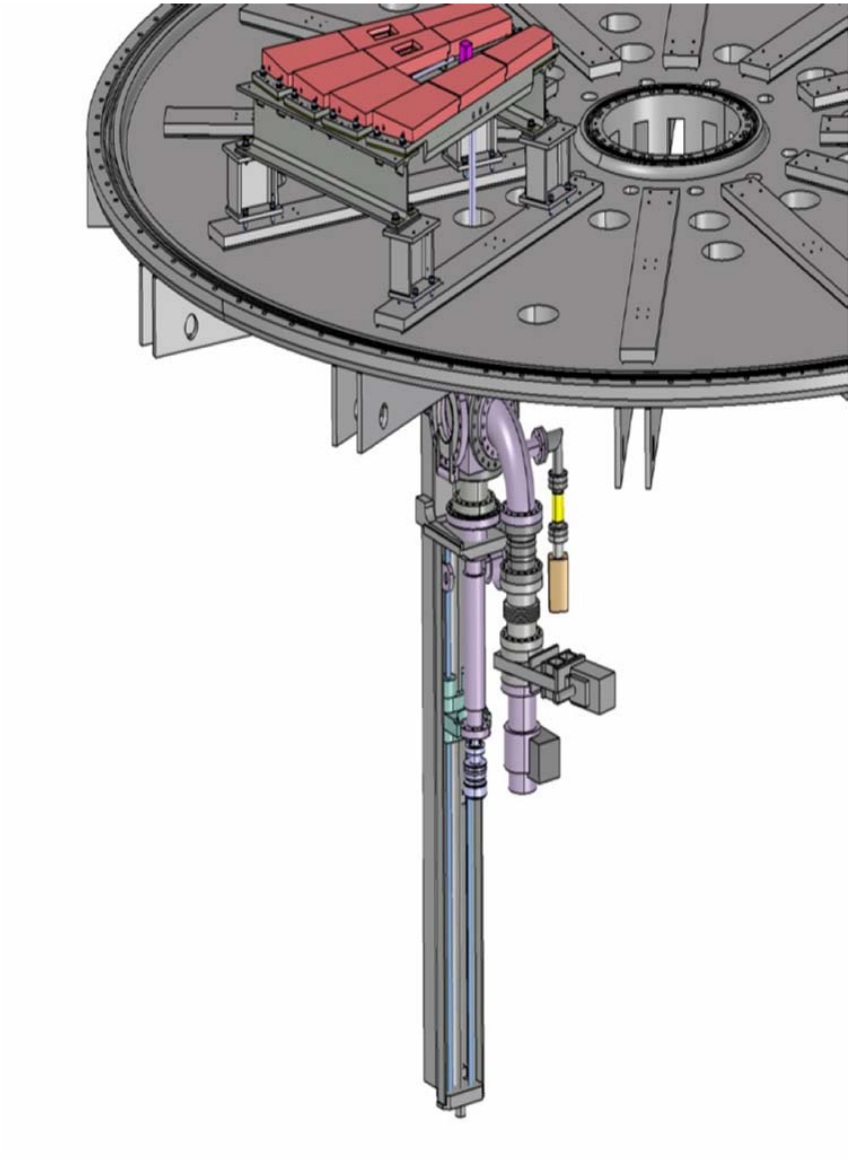
Results from a two-chord pilot system (in collaboration with VR Sweden) have confirmed the design approach of the planned MAST system:

- > 30 spatial channels, R = 0.8m – 1.4m
- Spatial resolution < 3 cm
- Thin-film filters, normal incidence – low cost, high transmission
- APD detectors
- Pitch-angle errors < 0.5°
- Time resolution < 5 ms

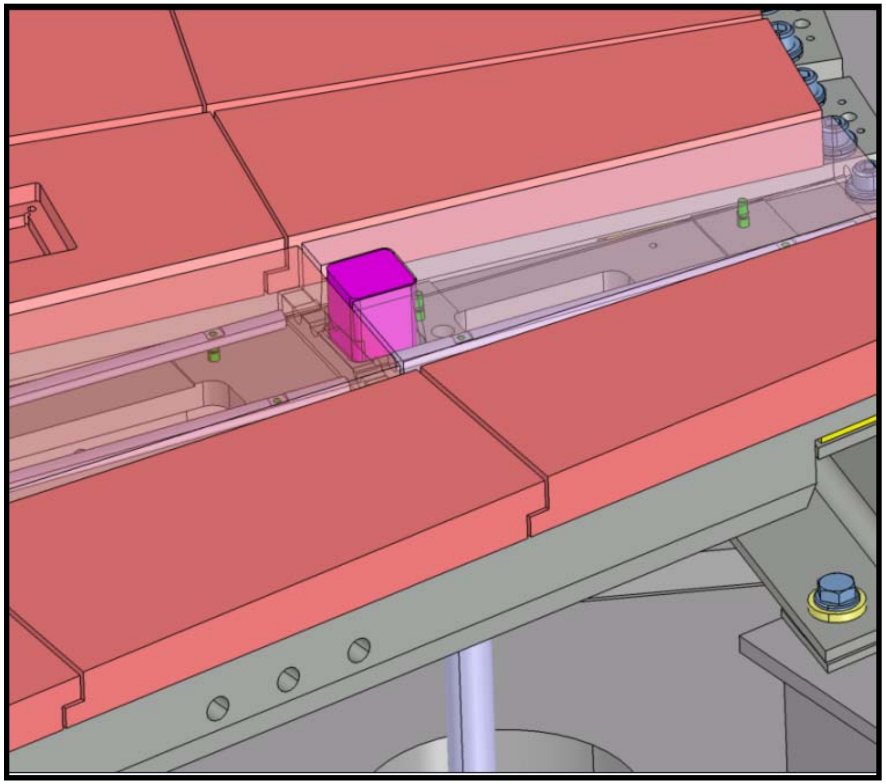


Installation Mar 2008

Divertor Science Facility



- erosion and transport of heavy impurities
- PFC tests, e.g. diamond (in conjunction with UK universities)



Present MAST status

- ELM coil installation was completed on 28 November (1 month ahead of milestone)
    - electrical installation almost complete
    - TAE electrical installation will be completed in April

- Both PINIs are installed and pumping
    - HV commissioning of new power supplies into dummy load starts ~ 28 Jan
    - Re - commissioning of existing PINI starts early Mar
    - HV commissioning of new PINI starts end Mar/beginning April

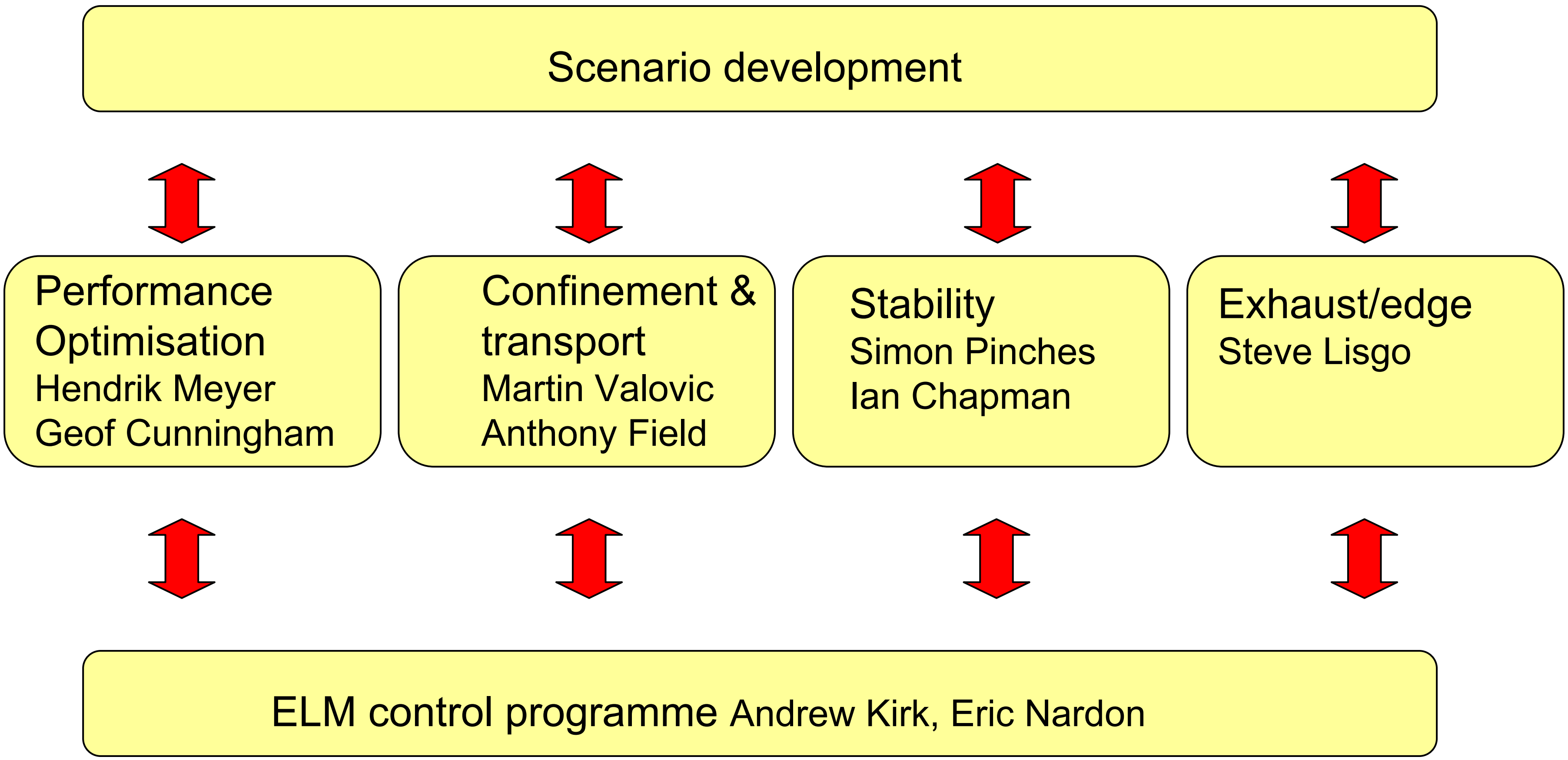
- Multi-chord MSE on schedule for installation by end of Mar (milestone due)

- Tender evaluation for new TS lasers and ADCs complete. Modification of existing lasers has started (first one done)

- Vessel closed up and pumping – leak checking underway. Hope to start high temperature baking end of this week

- First plasma late Mar, physics start late April, high power 2-PINI operation late May (assuming no major commissioning problems). Need to accommodate 28GHz gyrotron commissioning in May – impacts HVPS availability.

M7 (2008) organisation



ELM control experiments

ELM control experiments cut across all areas	
Performance Optimisation	H-mode optimisation - development of suitable target scenarios
Confinement & Transport	Impact of magnetic perturbations on global confinement, the edge pedestal (particle vs. energy transport) and interaction with pellet fuelling
Stability	Impact of magnetic perturbations on pedestal parameters and the link to ELM stability. Magnetic braking effects.
Exhaust	Impact of mitigation on ELM effluxes and divertor target power loads

Physics – forward programme (1)

❑ Confinement & transport

- ⇒ extend studies to higher P, I_p, (lower ν^*, higher β)
- ⇒ scaling with dimensionless parameters β, ε, ν^*
- ⇒ particle transport, including impurities & effects of shallow pellet injection on confinement (parameter scans, interaction with ELM control)
- ⇒ momentum transport studies
- ⇒ BES fluctuation measurements
- ⇒ transport barrier formation & sustainment, role of flow shear etc.*
- ⇒ comparison with transport models

❑ Stability

- ⇒ beta limit studies
- ⇒ fast particle instabilities – damping rate of intermediate-n TAEs incl. beta dependence (exploiting new TAE antenna)
- ⇒ sawtooth stability (co-/cntr-NBI, on-/off-axis deposition) *
- ⇒ neo-classical tearing modes – aspect ratio effects (e.g. with AUG)

* to include cntr-NBI

Physics – forward programme (2)

- **ELM/pedestal**
  - ⇒ ELM stability and control experiments using new ELM coils (incl. impact on confinement)
  - ⇒ ELM losses, target power loads (incl. new MAST/AUG/..IEA-ITPA joint experiment) and impact of mitigation
  - ⇒ small ELMs, incl. comparison with Type II ELMs on AUG (new IEA-ITPA joint experiment)
  - ⇒ pedestal scaling (e.g. T_e^{ped} width) & similarity studies
  - ⇒ pedestal fuelling & factors governing pedestal parameters

- **Exhaust physics**
  - ⇒ SOL turbulence & flows and comparison with available models
  - ⇒ radiative detached target scenarios at high beam power
  - ⇒ impact and optimisation of boronisation & GDC
  - ⇒ implementation of divertor science facility
    - \- erosion and transport of heavy impurities
    - \- PFC tests, e.g. diamond (in conjunction with UK universities)
  - ⇒ disruption studies (incl. possible implementation of disruption mitigation system)

….+ many other ('piggy-back') activities

Physics – forward programme (3)

- **Heating, current drive & start-up**
  - ⇒ extend NBCD studies to higher power, longer pulse duration & study dependencies*
  - ⇒ validate off-axis CD, impact of instabilities on fast ion distribution
  - ⇒ MSE measurements
  - ⇒ non-solenoid start-up and EBW-assist at higher power & pulse duration with ORNL gyrotron (power scaling)

- **Performance optimisation**
  - ⇒ H-mode optimisation at high power and plasma current
  - ⇒ routes to sustained regimes with high fusion gain
  - ⇒ H-mode with tolerable ELMs at low collisionality (incl. investigation of QH-mode access) *
  - ⇒ further optimisation of error field compensation

* to include cntr-NBI

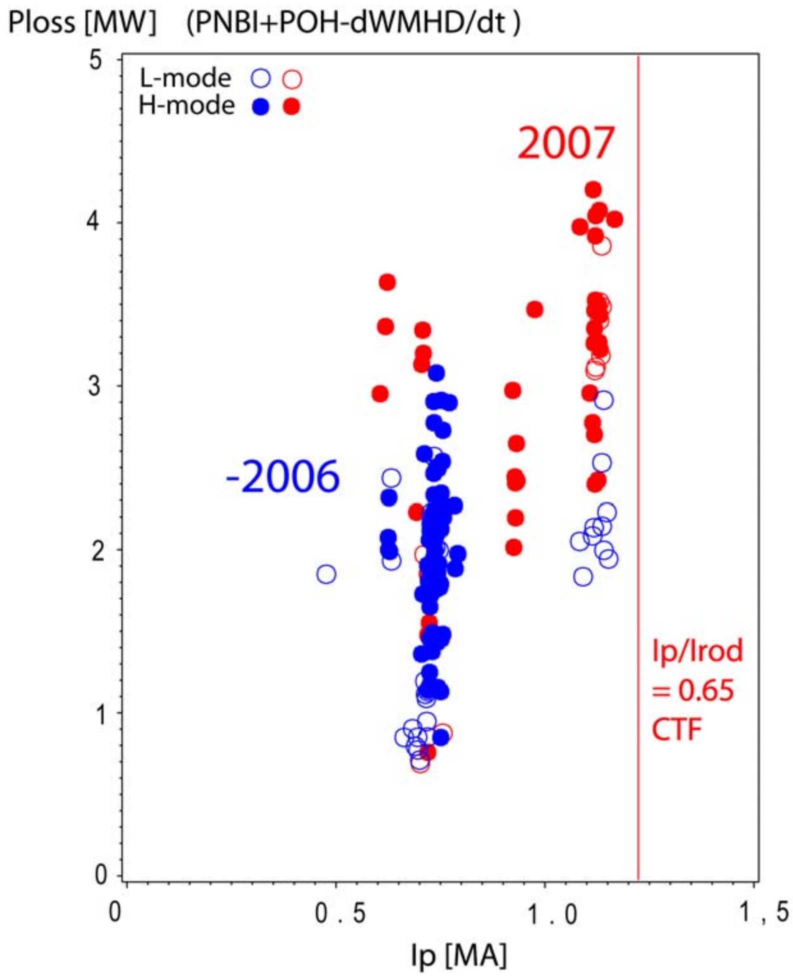
IEA-ITPA Co-ordinated Experiments 2008

EXP'T	**TITLE**
CDB-2	Confinement scaling in ELMY H-modes: beta degradation
CDB-6	Improving the condition of the global ELMy H-mode and pedestal databases: low A
CDB-9	Density profiles at low collisionality
CDB-10	*Power ratio hysteresis and access to H-mode with H~1*
TP-5	QH/QDB studies
TP-6.1	*Scaling of spontaneous rotation with no external momentum input*
TP-6.3	NBI-driven momentum transport study
TP-9	H-mode aspect ratio comparison
PEP-6	Pedestal structure and ELM stability in DN
PEP-9	NSTX-MAST-DIII-D pedestal similarity
PEP-10.1	The relationship between the fraction of ELM power arriving at the target and the filament radial propagation.
PEP-16	C-mod/NSTX/MAST small ELM regimes
PEP-19	Edge transport under the influence of resonant magnetic perturbations in DIII-D and TEXTOR.
PEP-21	The spatial and temporal structure of Type II ELMs

EXP'T	**TITLE**
DSOL-2	Injection to quantify chemical erosion
DSOL-3	Scaling of radial transport
DSOL-4	Comparison of disruption energy balance in similar discharges and disruption heat flux profile characterisation
DSOL-13	Deuterium co-deposition with carbon in the gaps of PFCs
DSOL-15	Inter-machine comparison of blob characteristics
DSOL-16	Determination of the poloidal fuelling profile.
DSOL-19	Impurity generation mechanism and transport during ELMs for comparable ELMs across devices
MDC-1	*Disruption mitigation by massive gas jets*
MDC-2	Joint experiments on resistive wall mode physics
MDC-4	*Neoclassical tearing mode physics – aspect ratio comparison*
MDC-5	Comparison of sawtooth control methods for NTM suppression
MDC-10	Measurement of damping rate of intermediate toroidal mode number Alfven eigenmodes
MDC-11	Fast ion losses and redistribution from localised AEs
MDC-12	Non-resonant magnetic braking
MDC-14	Rotation effects on NTMs
SSO-6	Ability to obtain and predict off-axis NBCD

Entries in italics are under consideration

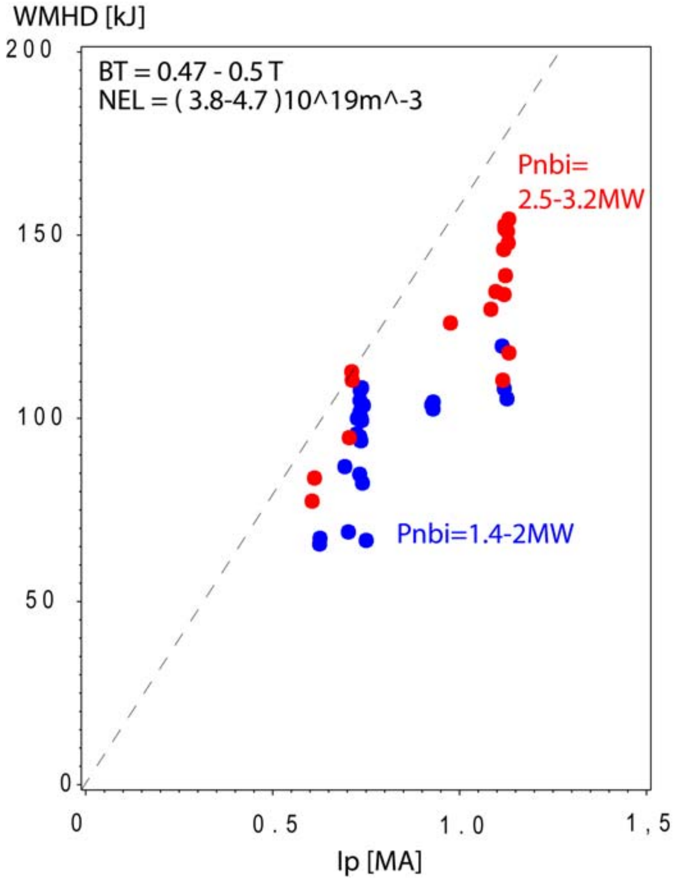
Expansion of MAST database 2007

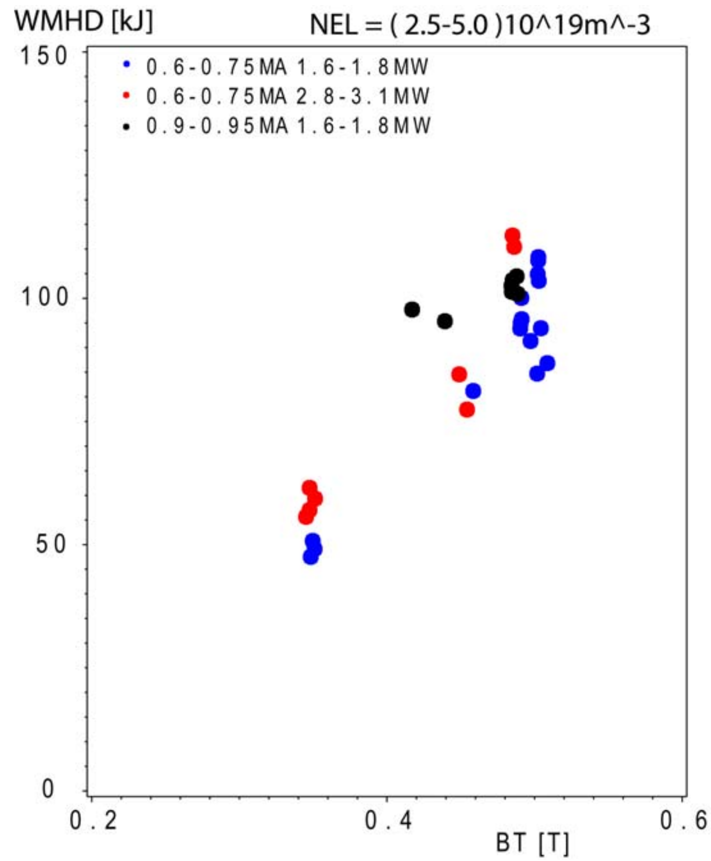


- Mainly focused on H-mode
- Towards relevant ratio of plasma to central rod currents
- Higher power

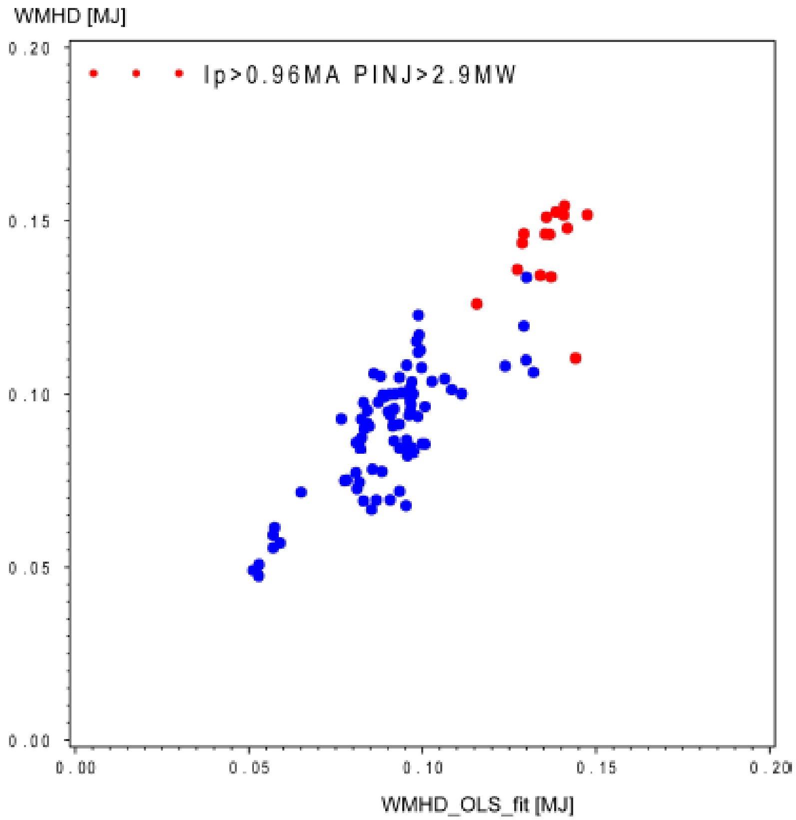
I_p and B_T scaling of τ_E

H-mode





I_p and B_T scaling of τ_E



H-mode

$$W_{mag} = C\, I_p^{\alpha I}\, B_T^{\alpha B}\, \overline{n}_e^{\alpha n}\, P_L^{\alpha P}\,.$$

Weaker I_p scaling, stronger B_T scaling than IPB98(y,2). Similar power scaling.

I_p scaling attributable to pedestal

Principle component analysis shows possible interplay between B and n exponents

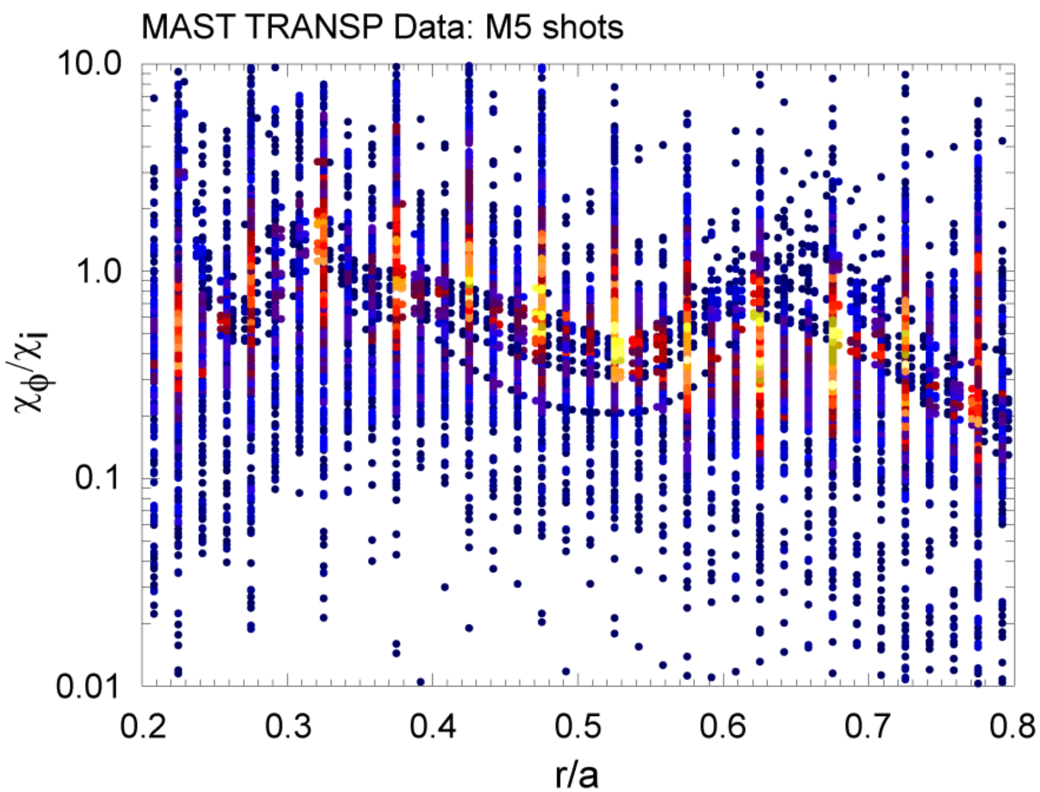
Table 1. Summary of scaling laws obtained by different methods.

	α_I	α_B	α_n	α_P	N	RMSE(%)
OLS	0.59	1.4	0.00	0.27	96	12.1
PCEIV	0.51	1.6	-0.06	0.39	96	
* OLS(I_p) [a)]	0.70	-	-	-	18	11

a) $I_p = (0.6-1.13)MA$, $B = (0.45-0.50)T$, $\overline{n}_e = (2.9-4.6)\times 10^{19} m^{-3}$, $P_{INJ} = (2.9-3.3)MW$

* narrower data set

Momentum transport

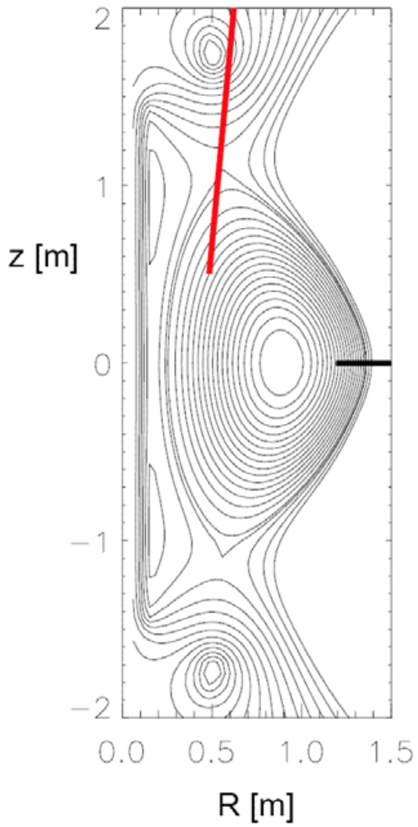


- Data from TRANSP analysis (colour indicates density of points)
- $0.3 < \chi_\phi/\chi_i < 1.0$ over most of plasma radius
- Momentum and energy transport appear to be linked

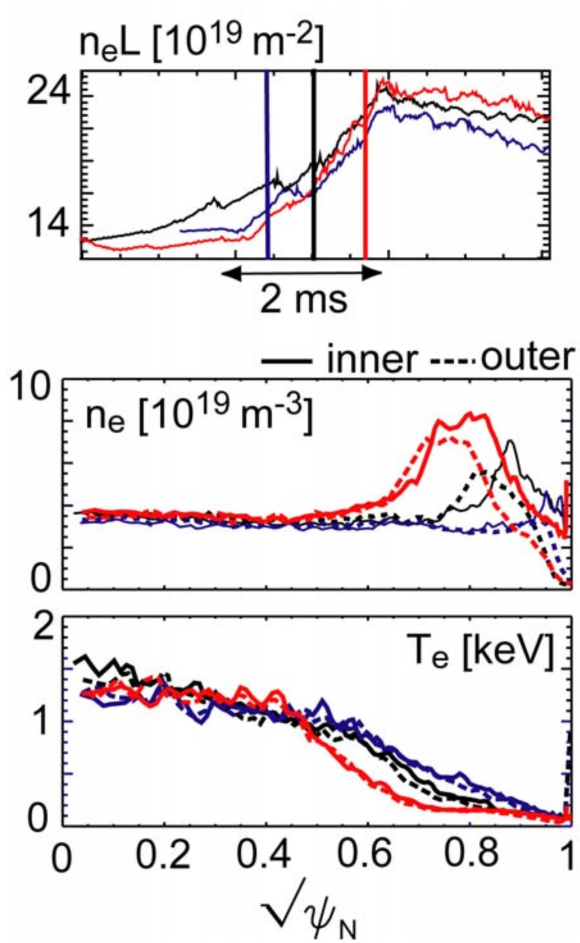
Fuelling - pellet injection

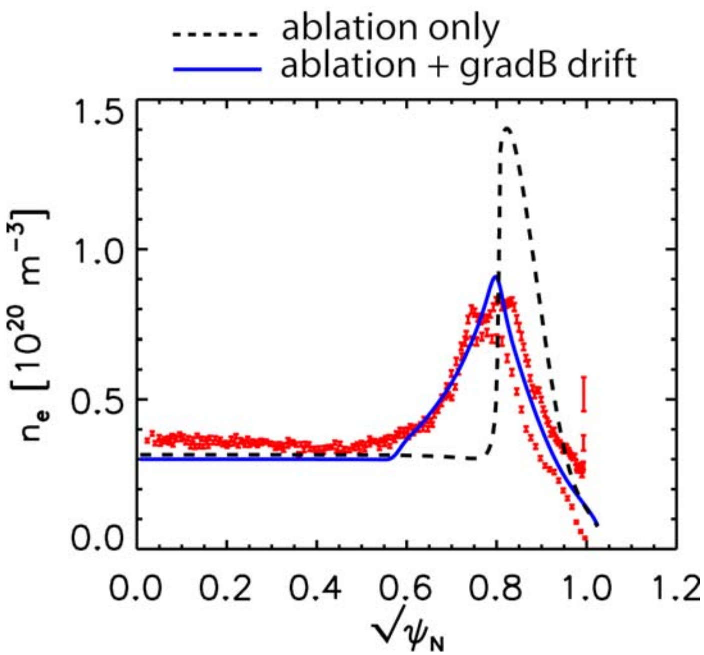
Top/inboard and mid-plane/outboard launch ≤ 6 pellets/pulse (FOM/Risø)

V_{pel} = 240 – 450m/s, shallow deposition



Profile evolution during ablation (allows separation of pellet deposition processes from post-pellet transport)



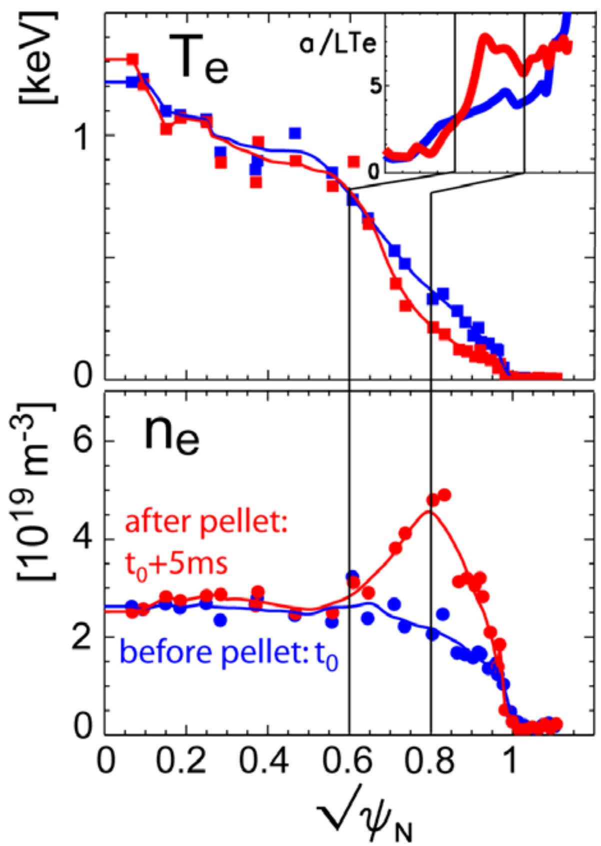


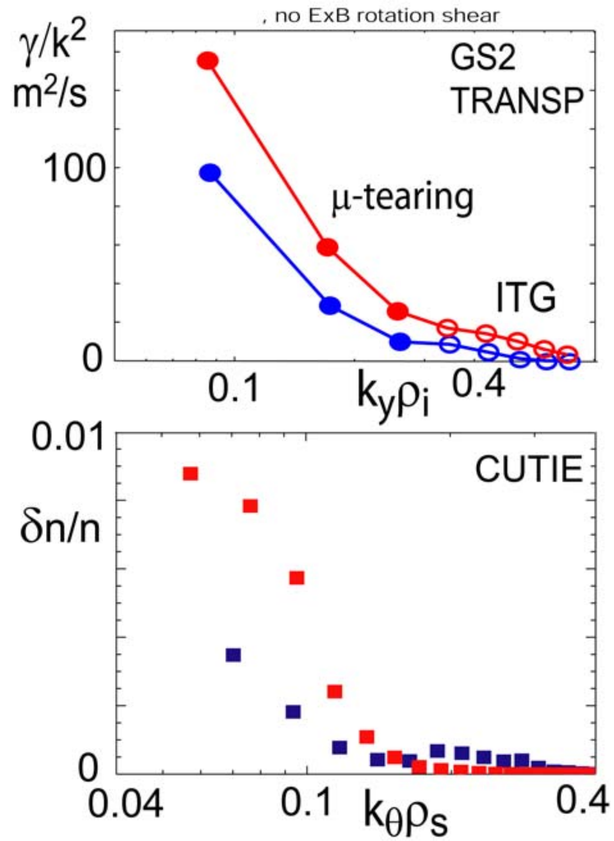
Pellet-triggered Thomson scattering

Top launch

Grad-B drift effects important

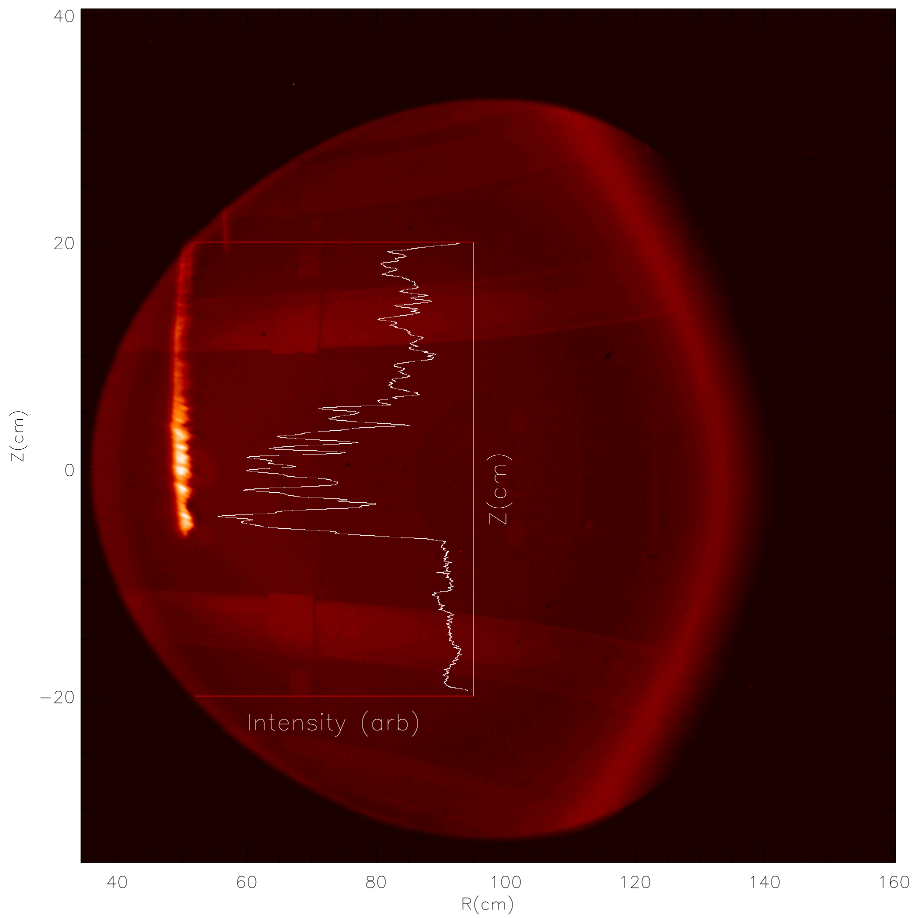
Pellet deposition: the inner zone





- Adiabatic deposition creates a distinct zone: $\nabla n_e > 0$, doubled $\nabla \ln T_e$
- Possibility of favourable increase of inward turbulence driven transport

Pellet ablation



Narrow band bremsstrahlung imaging (1.2mm/pixel) of pellet.

Visible bremsstrahlung measurements indicate:

- fine structure in emission intensity

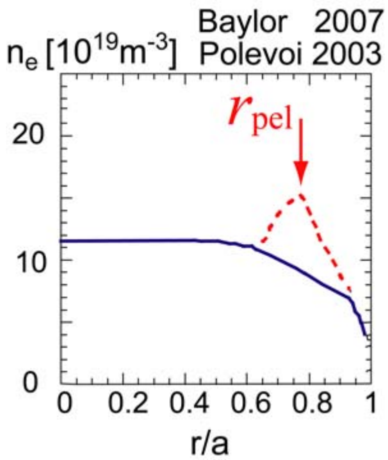
- ablatant density several orders of magnitude higher than background plasma

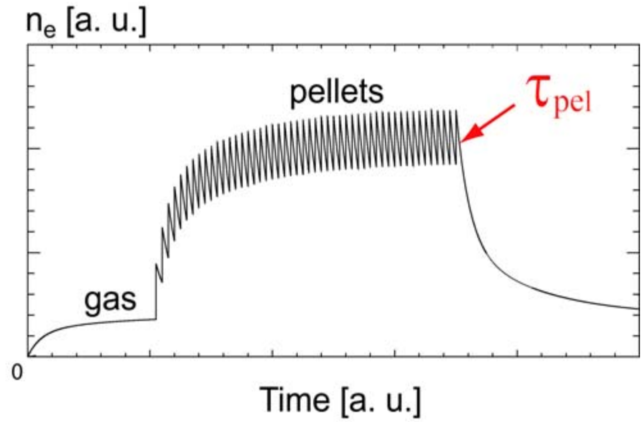
- sharp end of evaporation

Pellet ablation modelled by several codes including various processes (e.g. neutral gas shielding, grad-B drift effects etc) to understand better the ablation process (collaboration with HAS, CEA, ENEA).

Pellet fuelling of ITER like plasma

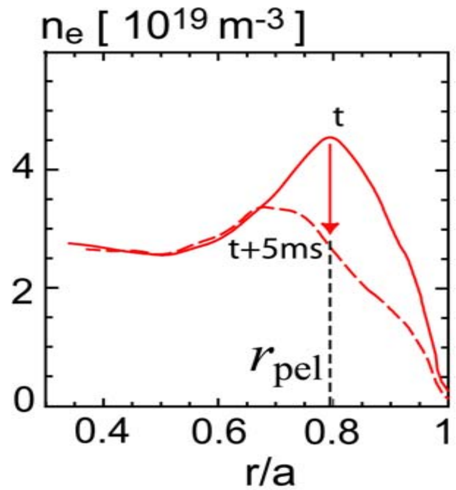
Shallow pellet injection in MAST mimics ITER situation



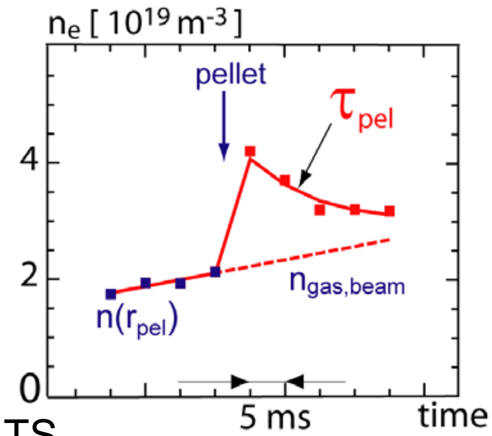


ITER

- New boundary for core confinement



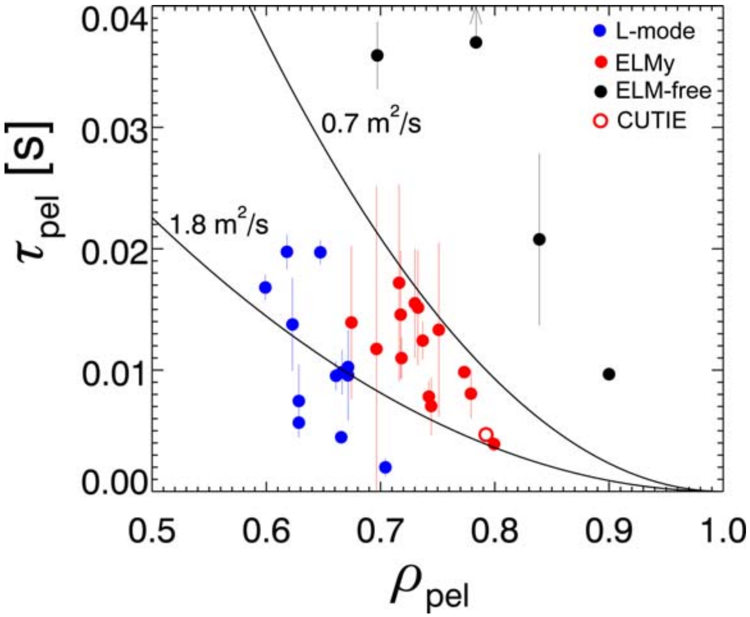
200 Hz TS

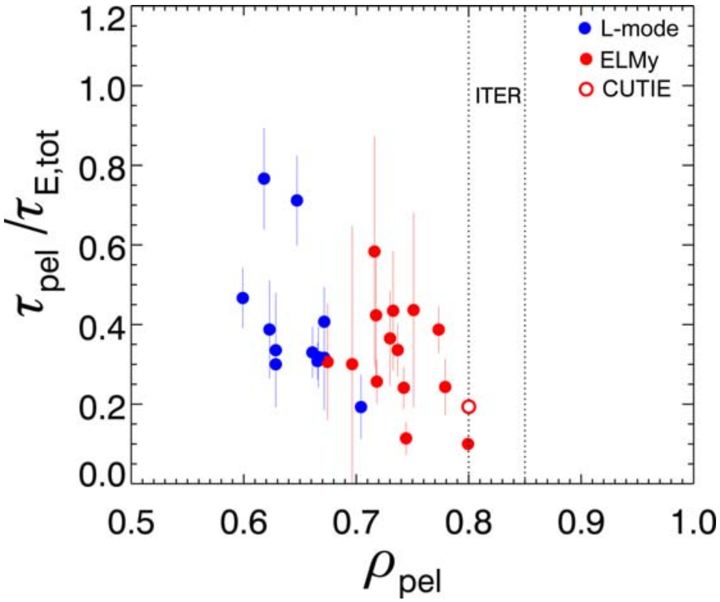


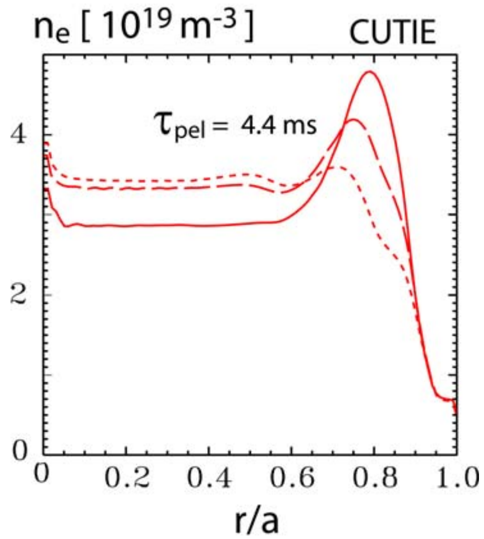
MAST

- Pellet deposition radius and retention time determine the required particle throughput

Pellet retention time correlates with status of ETB and pellet deposition depth







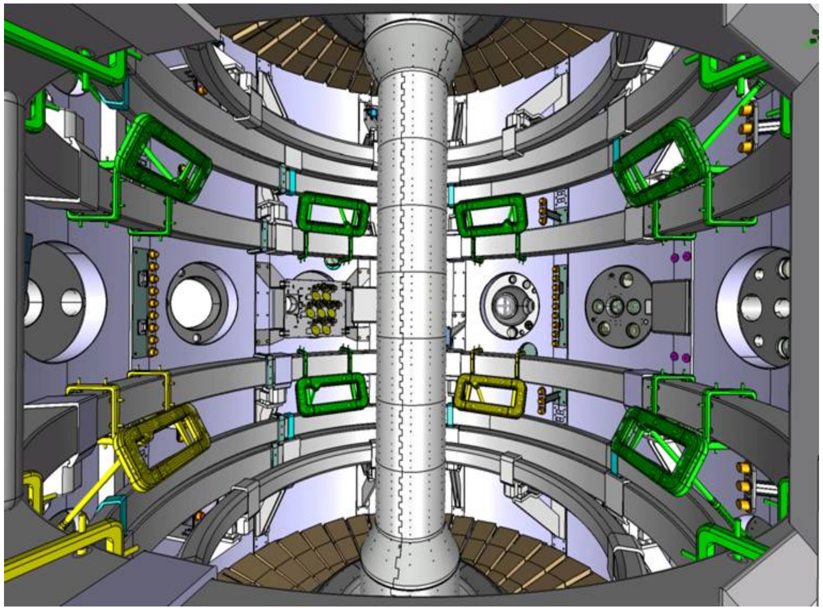
Extrapolation to ITER indicates particle throughput:

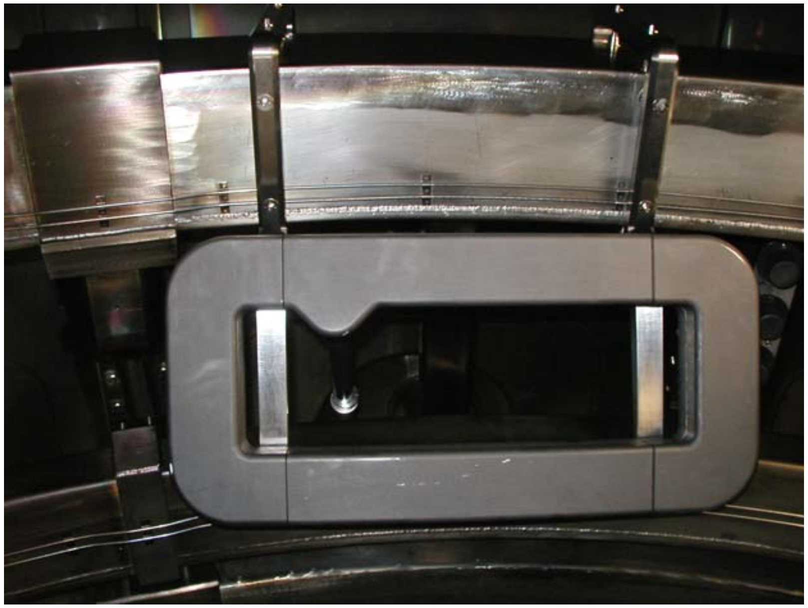
$$\phi_{pel} = 70 Pam^3/s$$

i.e. 70% of design value in steady-state

CUTIE simulation in good agreement

Active TAE antennas in MAST





2007: Trial with 3-coil set 10A, 0.5MHz

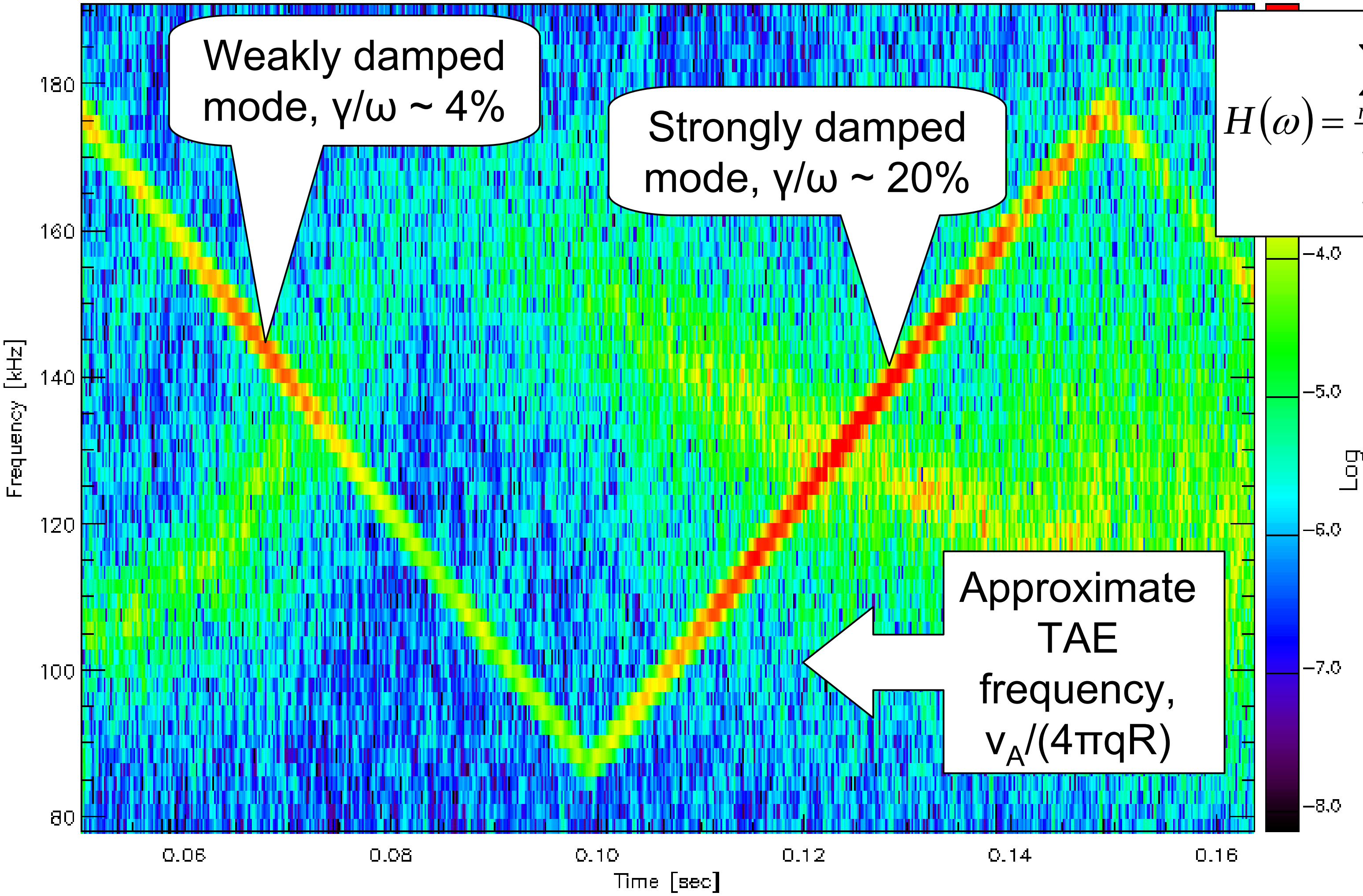
2008: 2x6 coil arrays (upper/lower)
- to be used also for ELM control at ≤ 2kA dc

Mode damping in presence of super-Alfvénic NBI

Damping measurements over large range of β values

Collaboration with Imperial College, York Univ., Warwick Univ.

Active Excitation of AE by Antenna

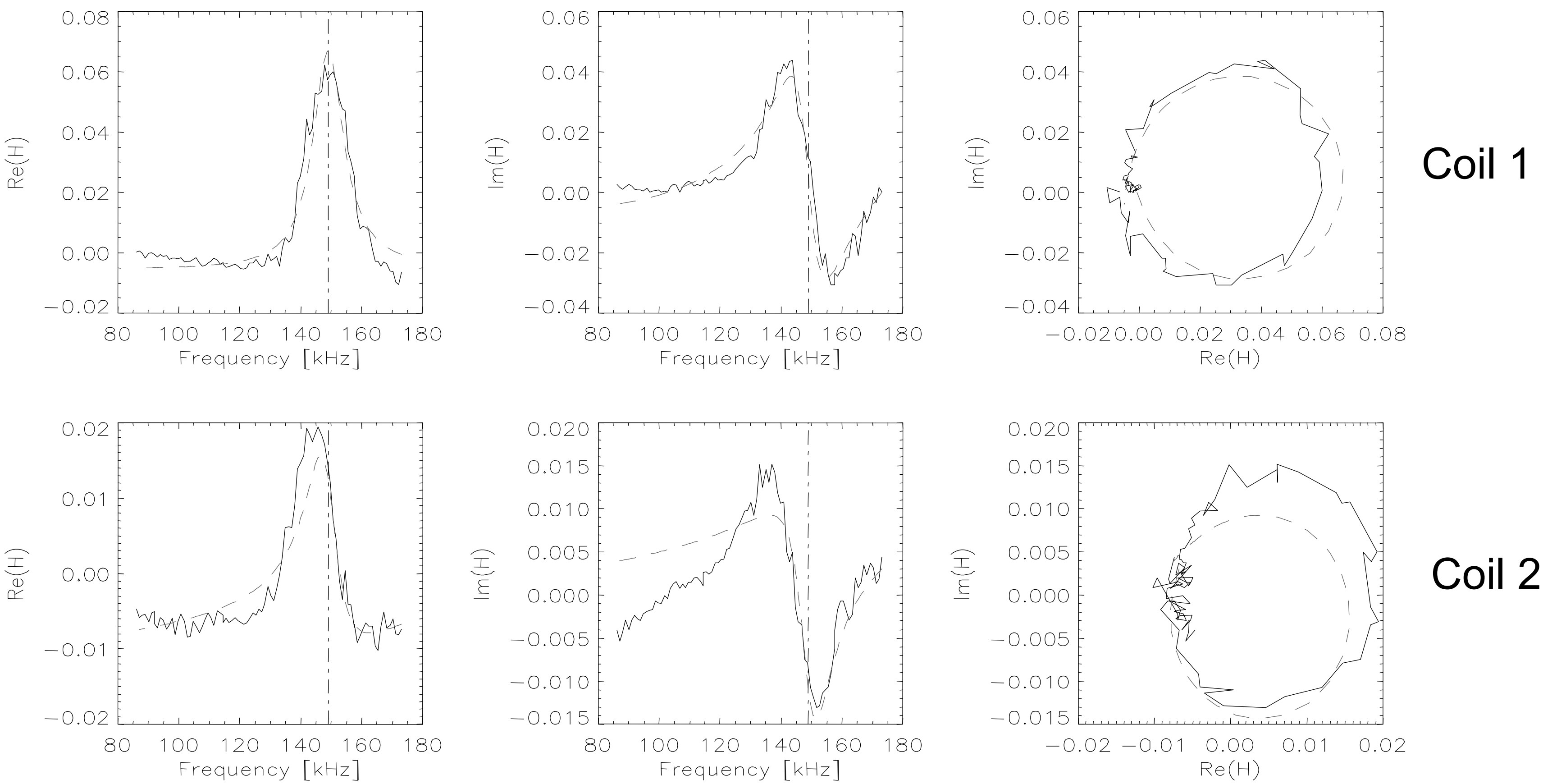


$$H(\omega) = \frac{\sum_{m=0}^{M} b_m (i\omega)^m}{\sum_{n=0}^{N} a_n (i\omega)^n}$$

- Antenna excites stable plasma modes in MAST #18487
- Fitting system transfer function identifies damped modes

Resonance in MAST #18487

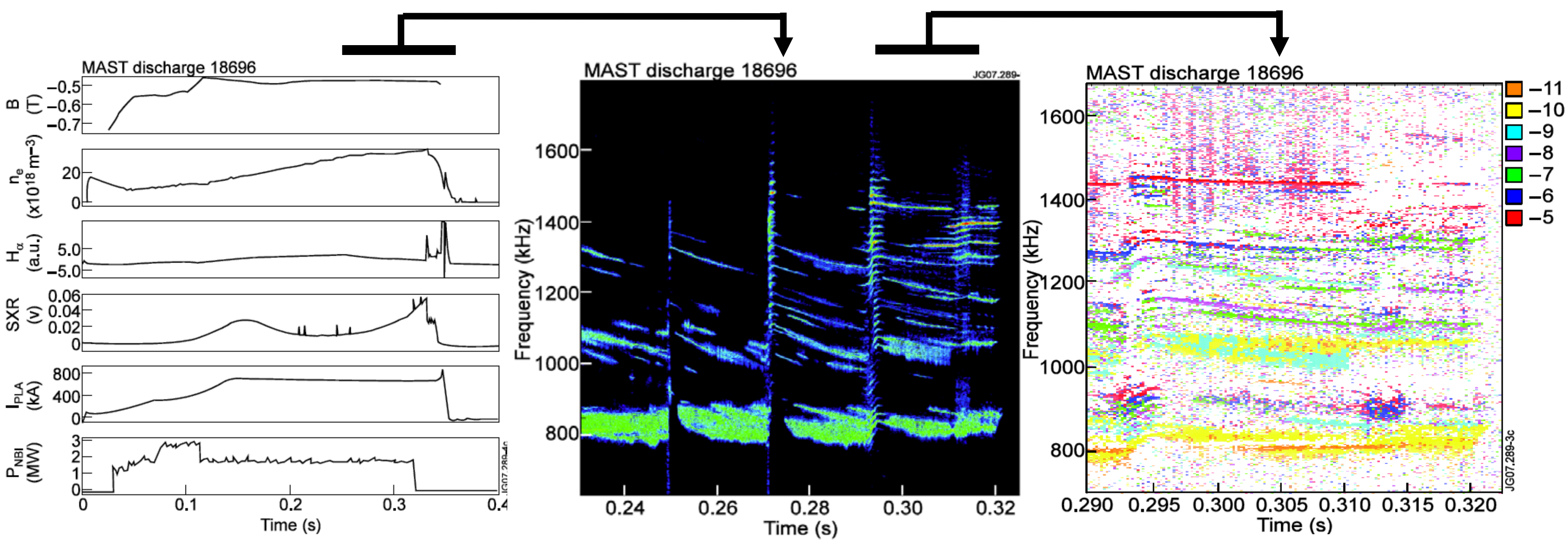
Software synchronous detection using multiple high frequency magnetic coils



Shot	Time [ms]	Frequency [kHz]	Damping [%]
18487	64.6	148.9	4.15

High frequency modes

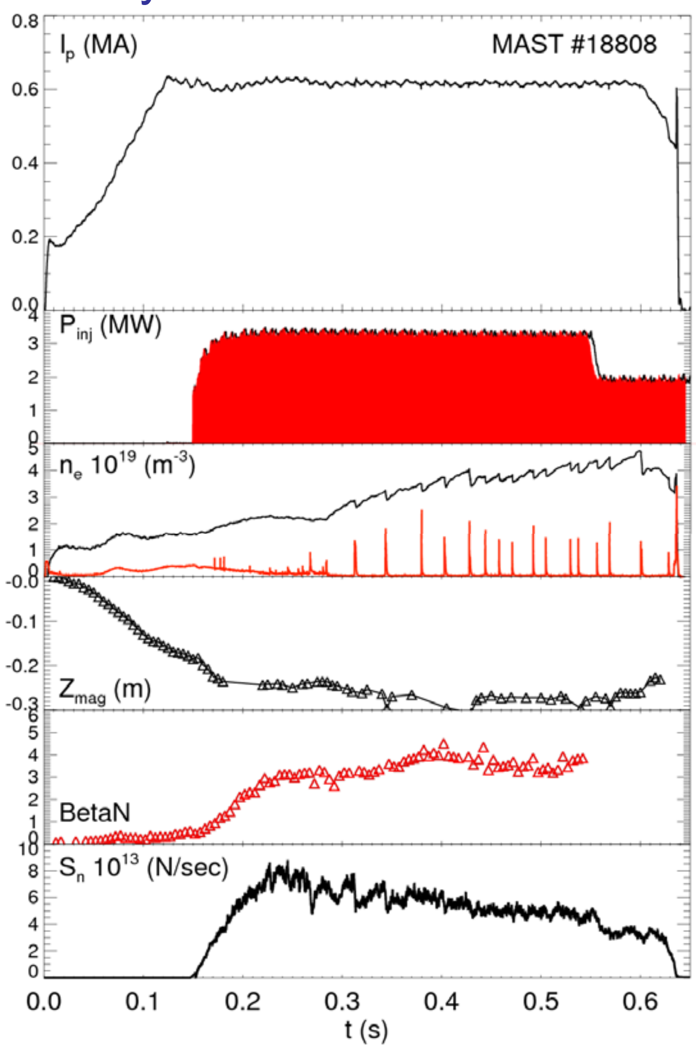
- High-frequency modes observed on MAST, f ~ 3.8 MHz
  - Magnetic coil sampling frequency 10MHz
- Broad frequency range: 0.4 → 3.8 MHz (above ω_{ci0})
  - Frequency splitting often observed
- Toroidal numbers typically between |n| = 4 and |n| = 10
  - Both positive and negative mode numbers observed
- Similar to CAE/GAE observed on NSTX



M Lilley (Imperial College), H Smith (Warwick University)

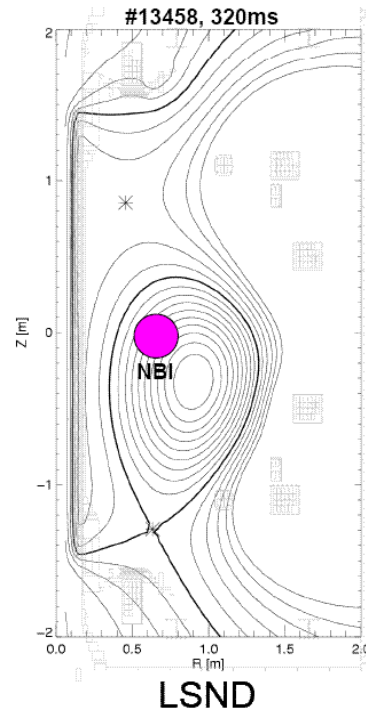
Off-axis NBCD

Large MAST vessel allows exploratory studies of off-axis NB heating & current drive in vertically displaced SND plasmas – extended to higher power and density in 2007

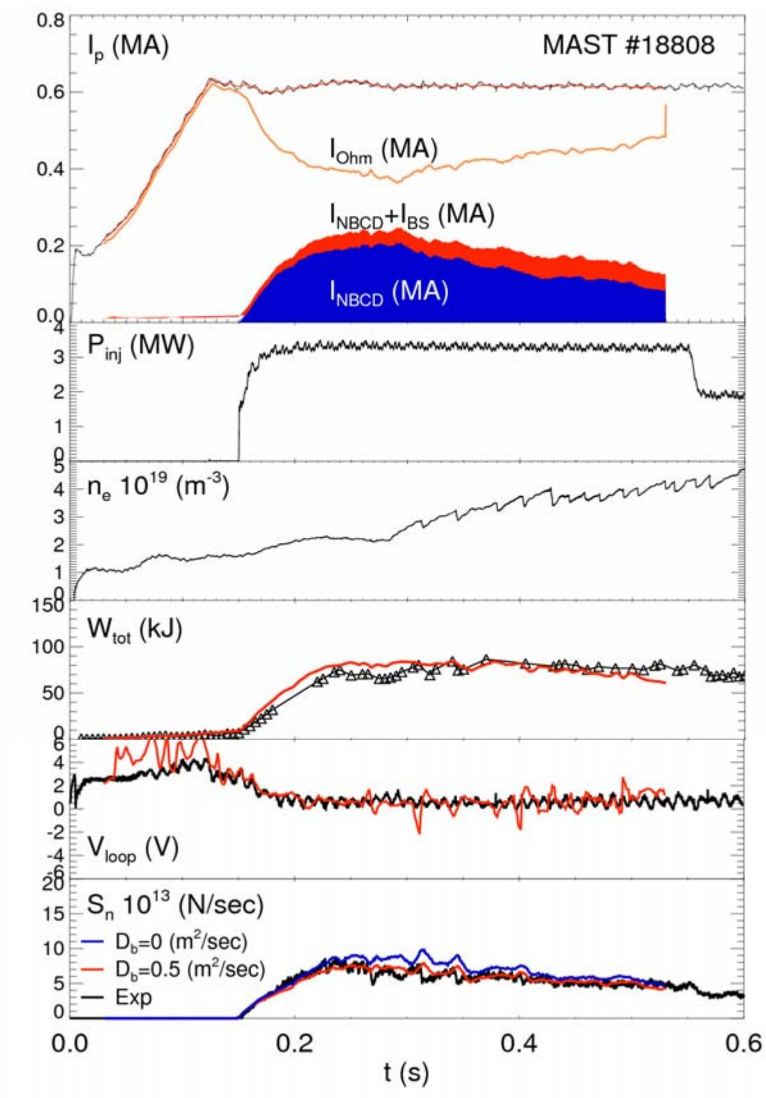


0.5s flat-top, 350ms H-mode (limited by ORNL NBI & solenoid I^2t)

High sustained β_N (3.5 - 4)



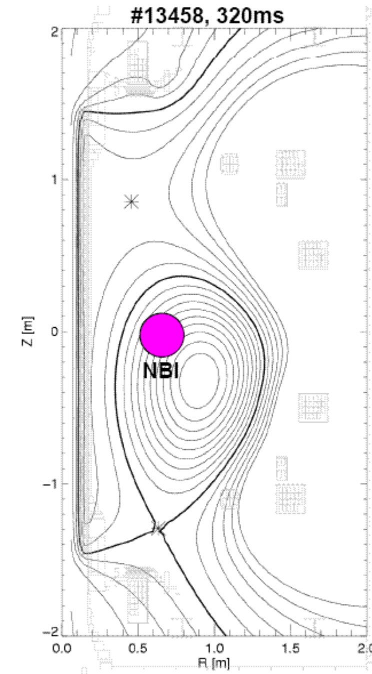
Off-axis NBCD



TRANSP:

I_{NBCD}/I_p ~ 30%

Anomalous fast ion diffusion ($D=0.5m^2/s$) introduced to better match neutron rate – decreases in neutron rate correlate with bursts of high frequency MHD (10 – 30kHz)



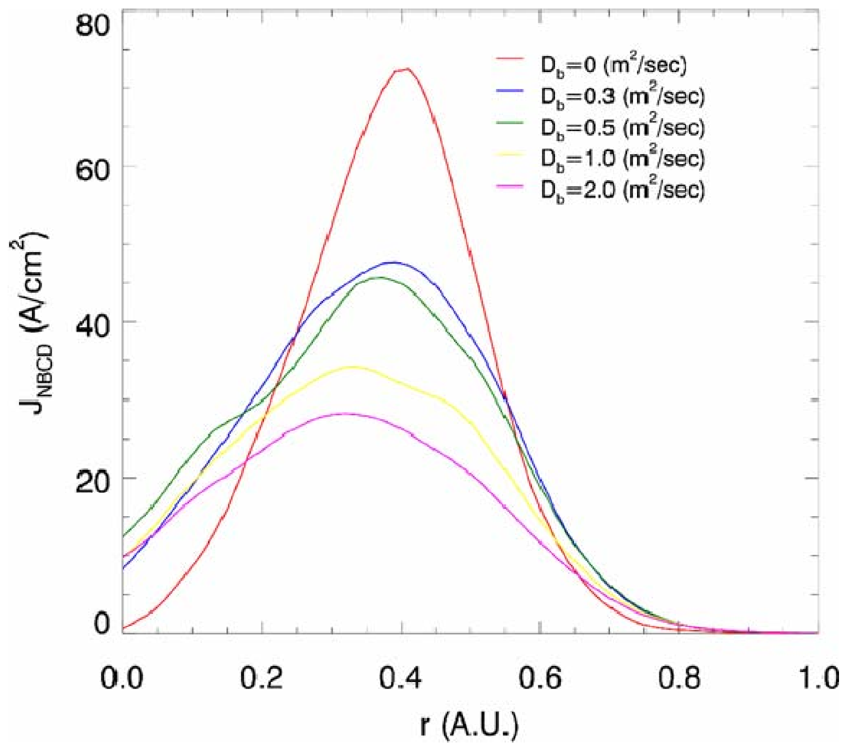
LSND

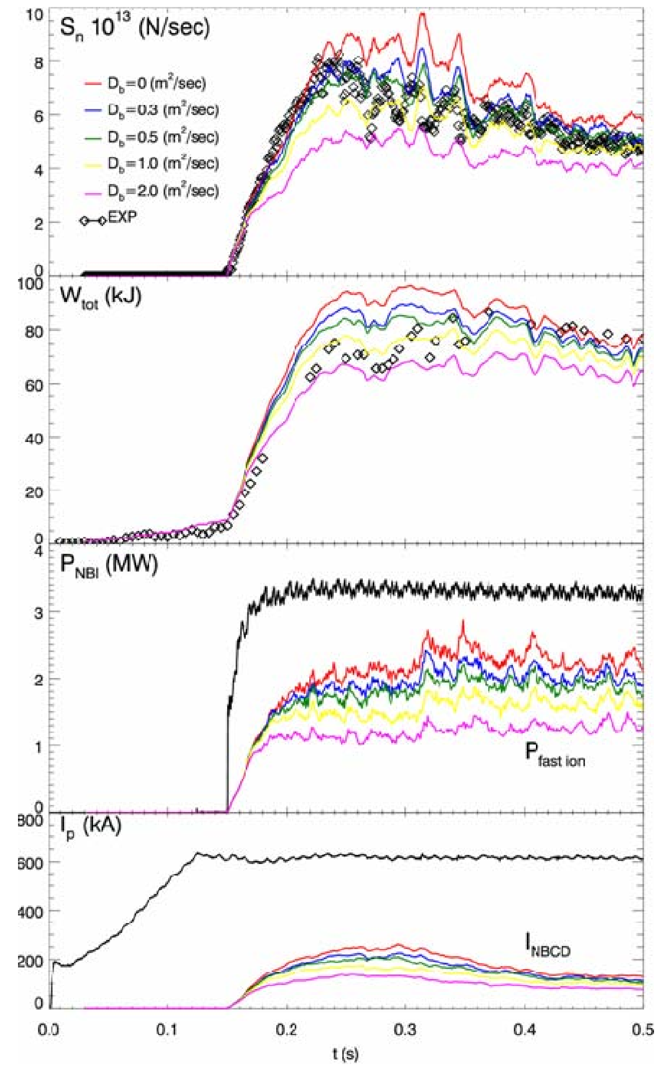
Need to demonstrate that efficient off-axis current drive is retained at higher power (cf. AUG) and confirm driven current profile by 'direct' measurement

Replace ORNL source by PINI (higher power, longer pulse studies) and implement MSE in 2008

Off-axis NBCD

Effects of anomalous fast ion diffusion

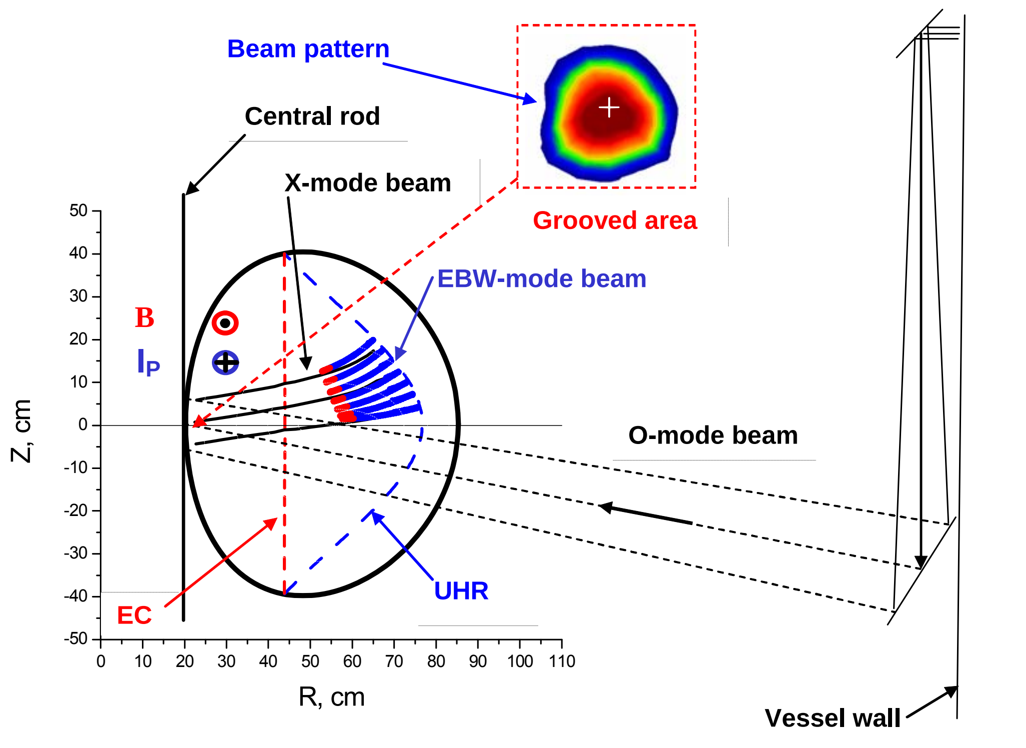


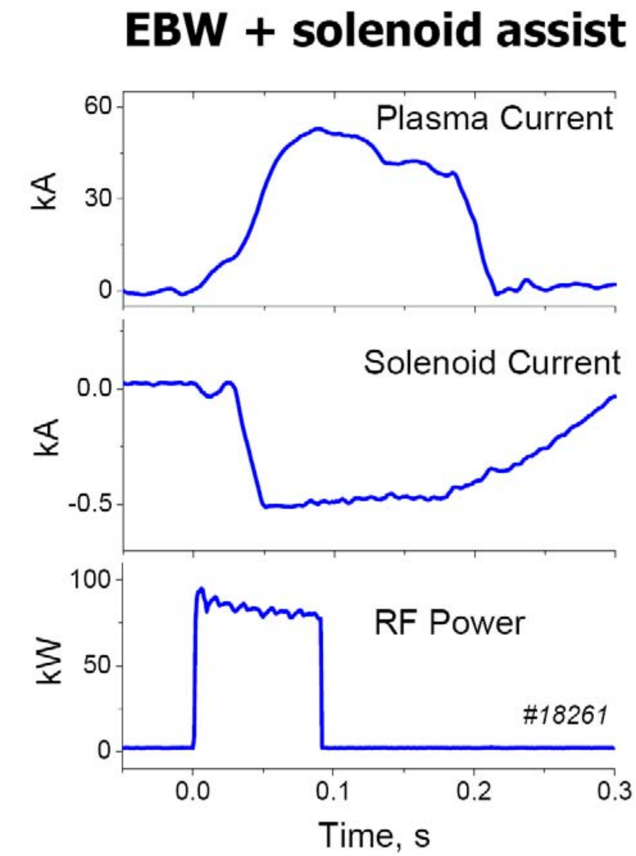


D_b (m^2s^{-1})	0	0.3	0.5	1.0	2.0
I_{NBCD}(kA)	253	221	209	164	130
I_{NBCD}/I_p (%)	41	36	34	27	21

D assumed independent of energy and pitch angle here – presently exploring effects of limiting D in energy and pitch angle space

EBW start-up (28GHz)



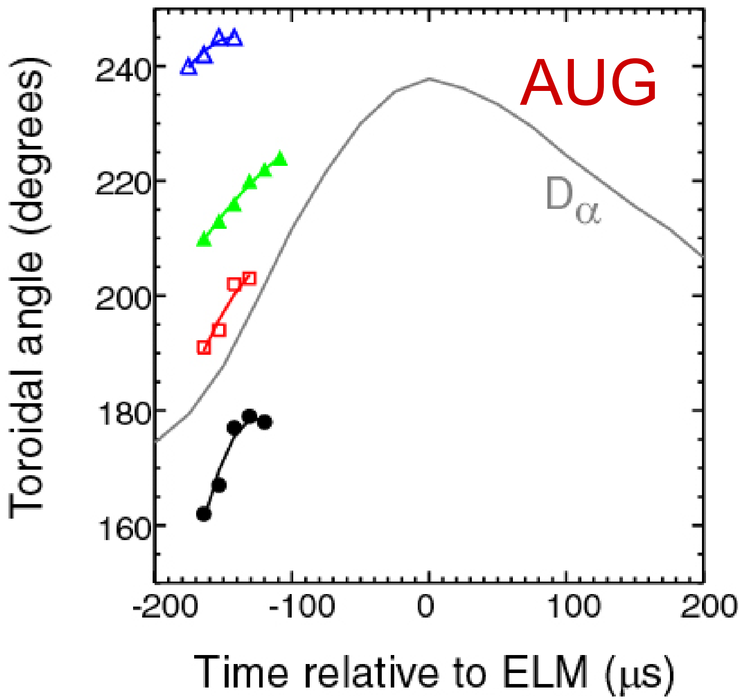


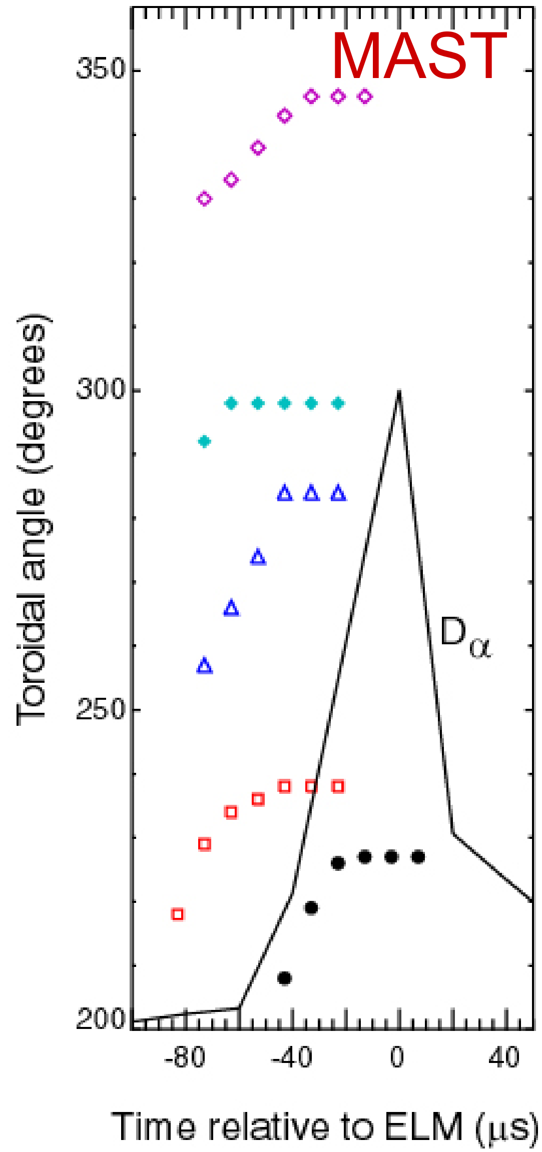
P_{EC} ~ 100kW, 28GHz

- ❑ Up to 33kA generated by EBW without solenoid flux
- ❑ Up to 55kA generated by EBW + limited solenoid flux (~ 0.5% of full swing)
  - mimic iron core or removable solenoid in the CTF
- ❑ Plan to install higher power (350kW), long pulse 28GHz gyrotron (on loan from ORNL) in 2008.

ELM filament propagation

ELM filaments in MAST & AUG exhibit similar characteristics





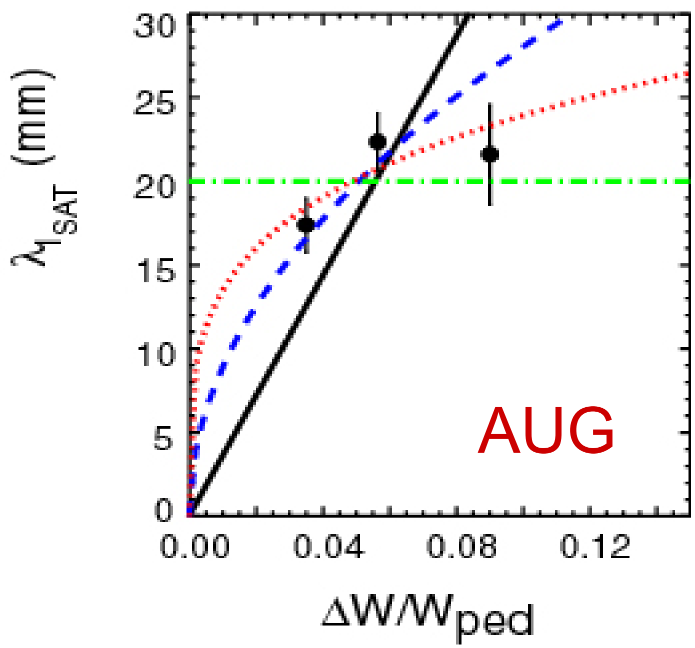
- The filaments are observed to rotate in the co-current direction, initially with the pedestal velocity, decelerate toroidally and move out radially with velocities of ~ kms^{-1}
- Filaments leave the LCFS at different times
- The width of each filament is ~ constant in time

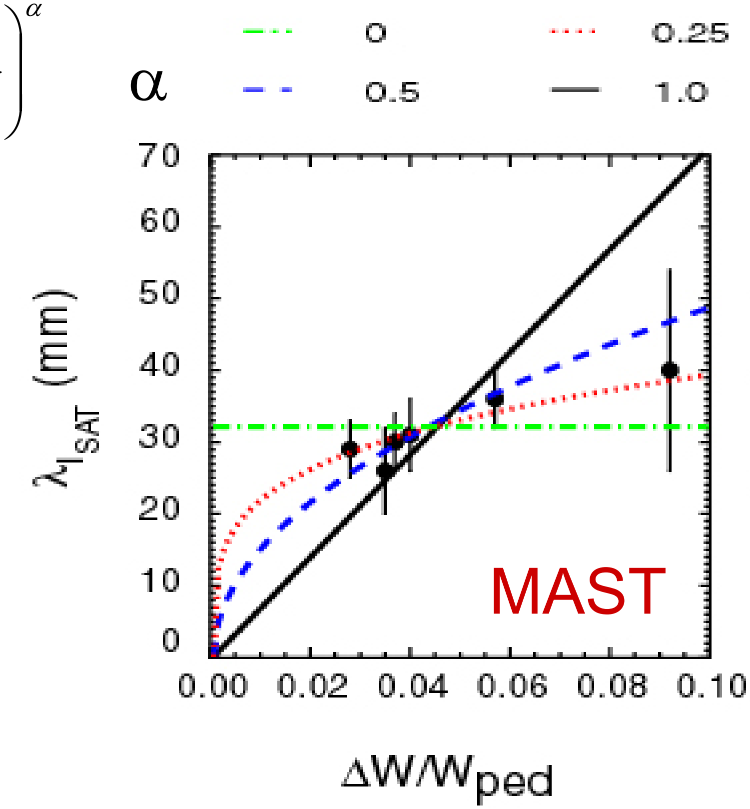
Scaling with ELM size

PEP-10

$\lambda_{ISAT} \sim \lambda_q$ (AUG)

Fitted with $$\lambda \propto \left(\frac{\Delta W_{ELM}}{W_{ped}}\right)^{\alpha}$$

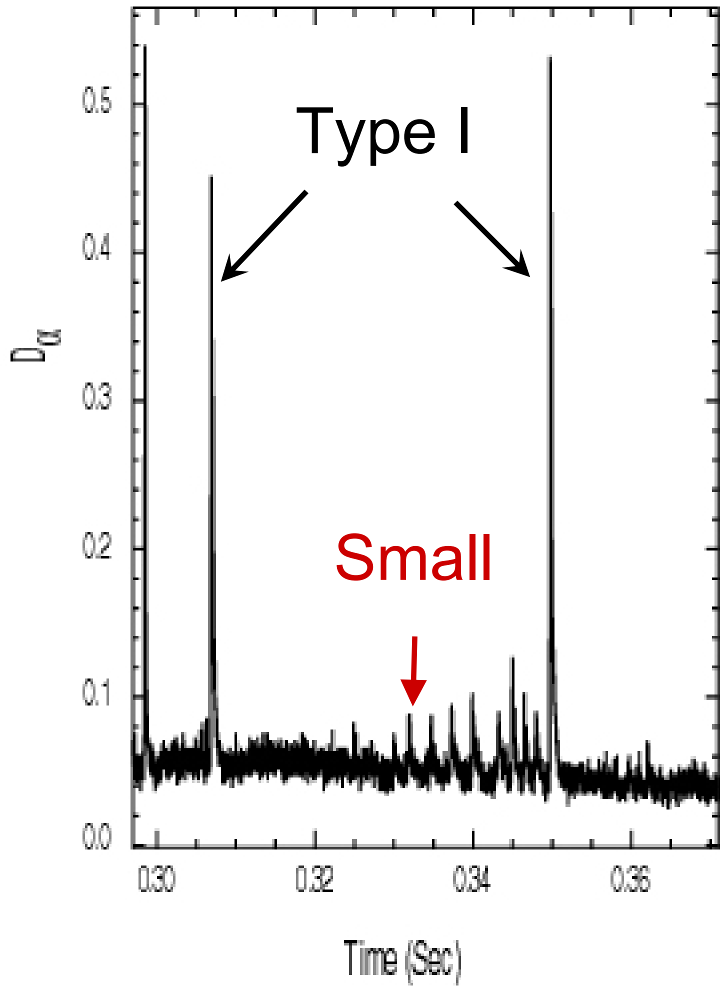


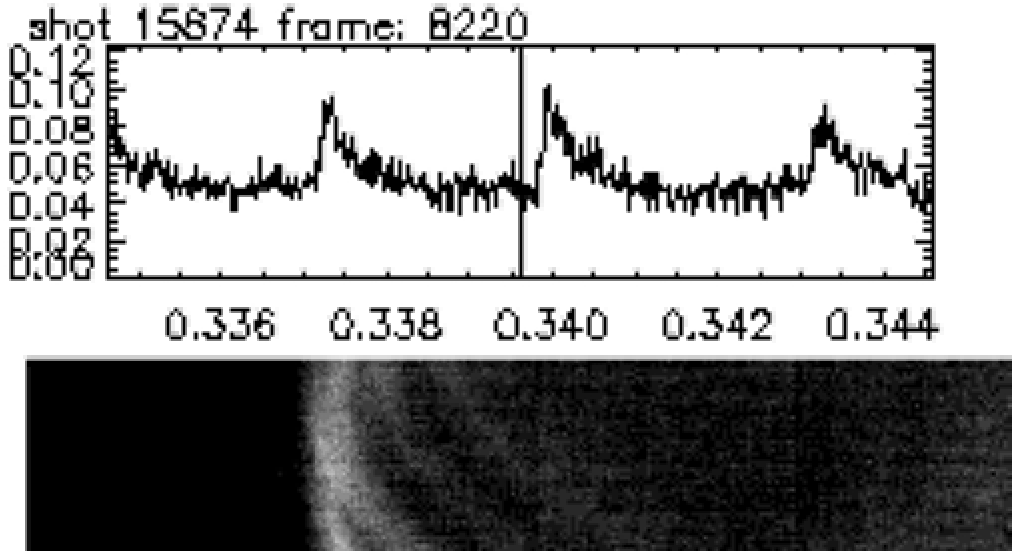


- ❑ Weak dependence of λ_{ISAT} on size of ELM in AUG and MAST

- ❑ Fraction of energy arriving at the divertor in JET, requires both a strong increase in λ with $\Delta W_{ELM}/W_{ped}$ and also that the fraction of energy carried by the filaments is larger than measured experimentally. Future experiments aimed at understanding these discrepancies.

Small ELM regimes in MAST

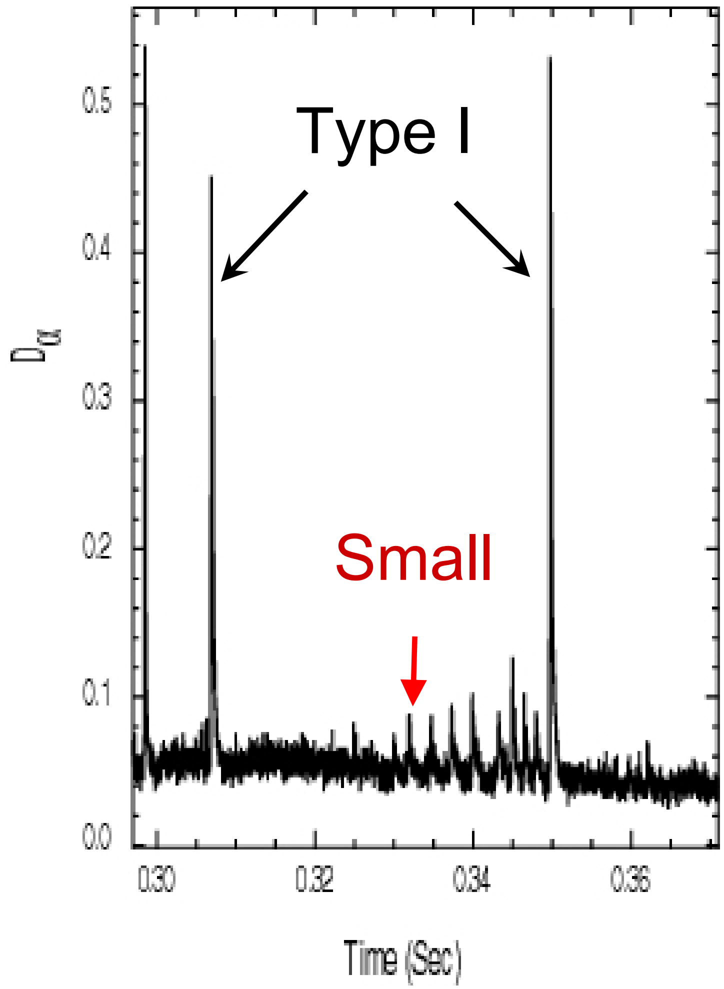


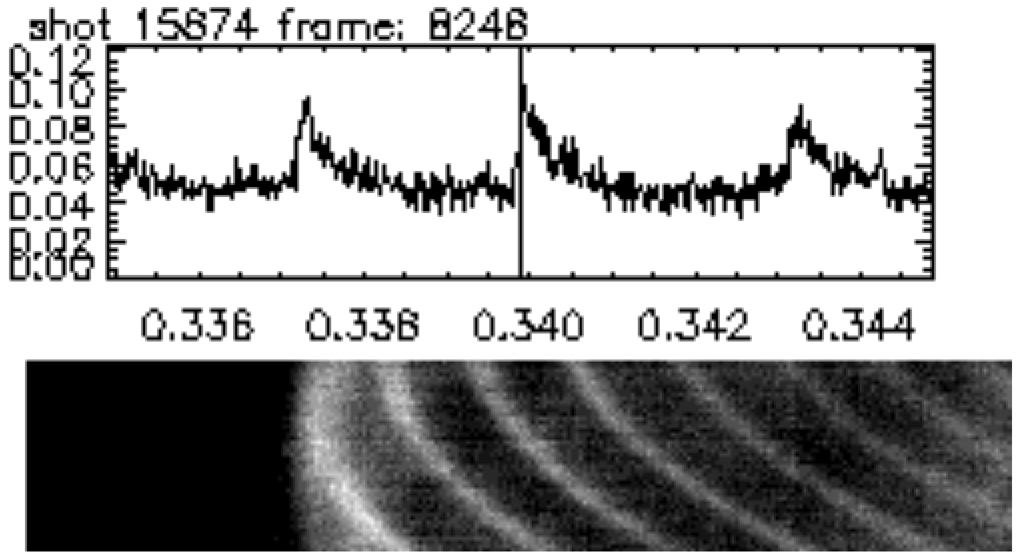


- Usually mixed in with larger ELMs – not a useful regime so far

- Linked to inter-ELM filaments which seem to grow into 'small' ELMs

Small ELM regimes in MAST





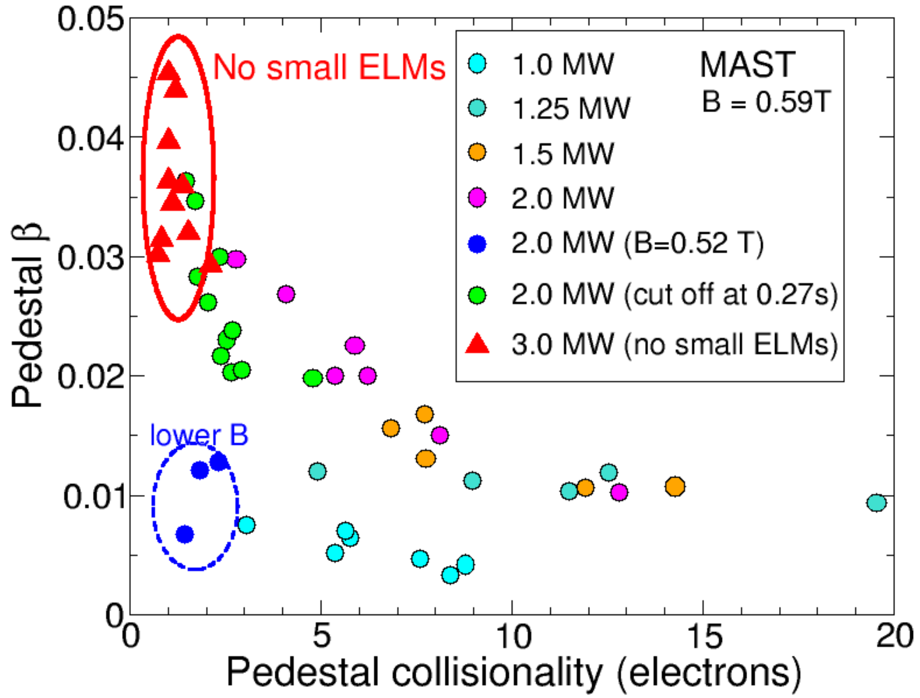
- Very regular structure
- Very little evidence for a radial expansion

Small ELM regimes in MAST

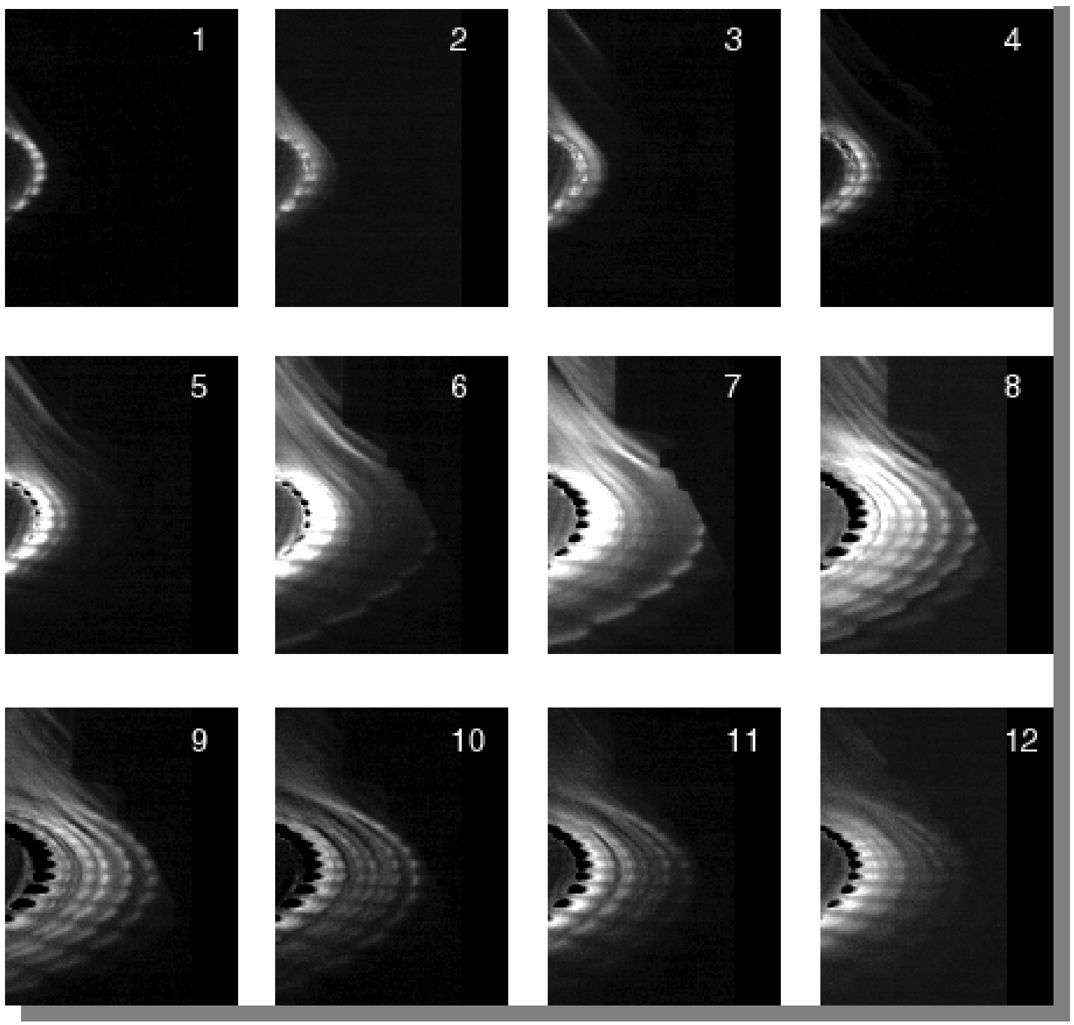
PEP-16

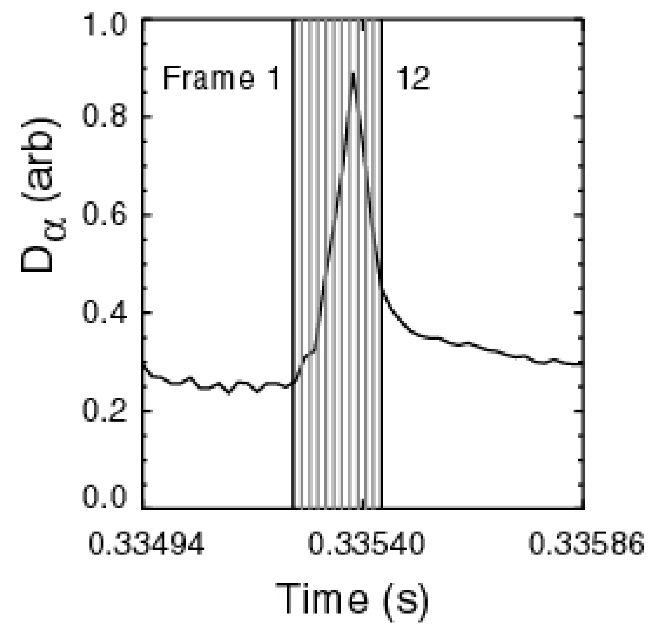
MAST/NSTX/C-MOD comparison – similar dimensionless pedestal parameters

- Small ELMs exist over a wide range in ν^* and β_{ped}.
- At low power they are mixed with type-III ELMs
- Small ELMs disappear at high power and low collisionality $\nu^* < 1.5$ and high β_{ped}^{LFS}
- High n filaments rotate co-current, not all of them detach.
  larger ELMs: all filaments detach, medium n.
- The characteristics seem different from type-V ELMs.



ELM interaction with divertor target



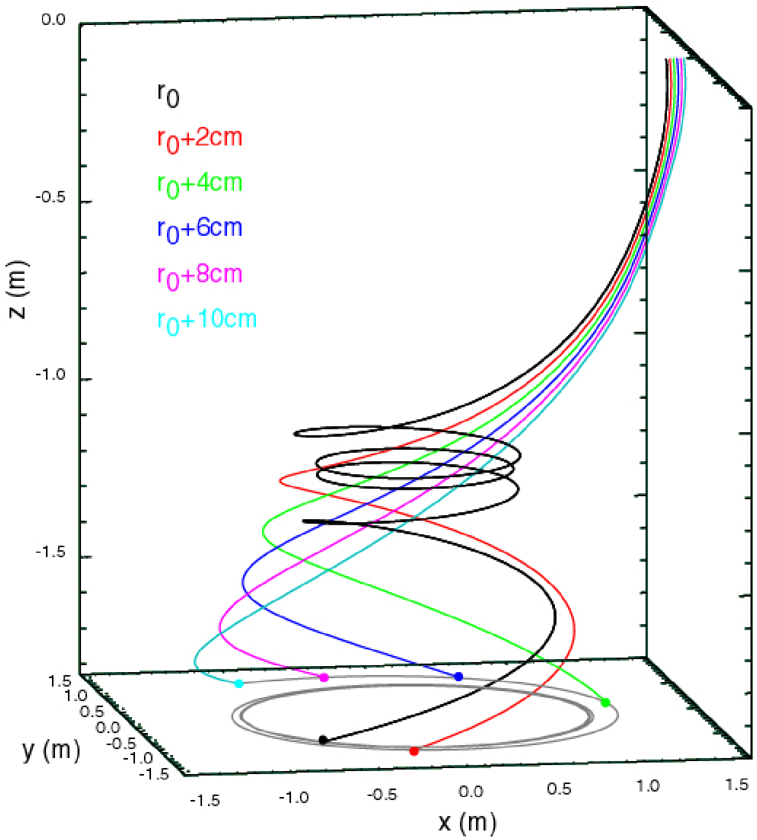


No first wall interactions in MAST

Filament energy deposited at target

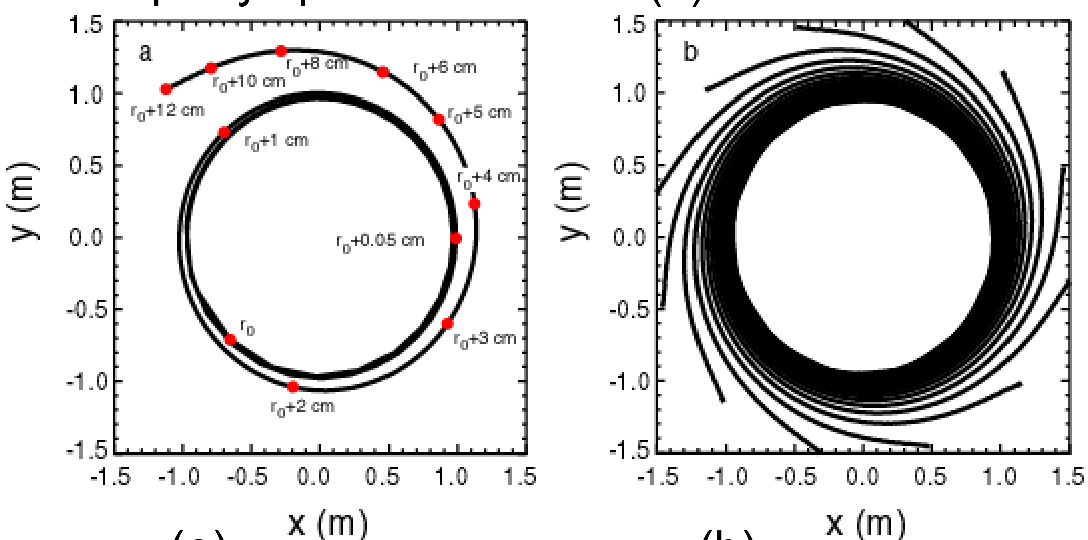
ELM interaction with divertor target

Field lines in the SOL



Modelling reproduces divertor footprint

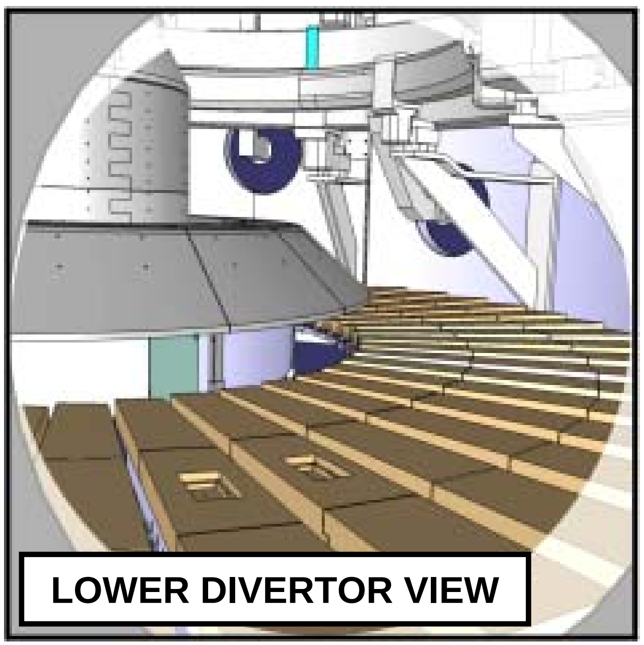
Predicted divertor target pattern due to filament with a mid-plane toroidal extent of 5°expanding radially by 12cm (a) or 12 equally spaced filaments (b)

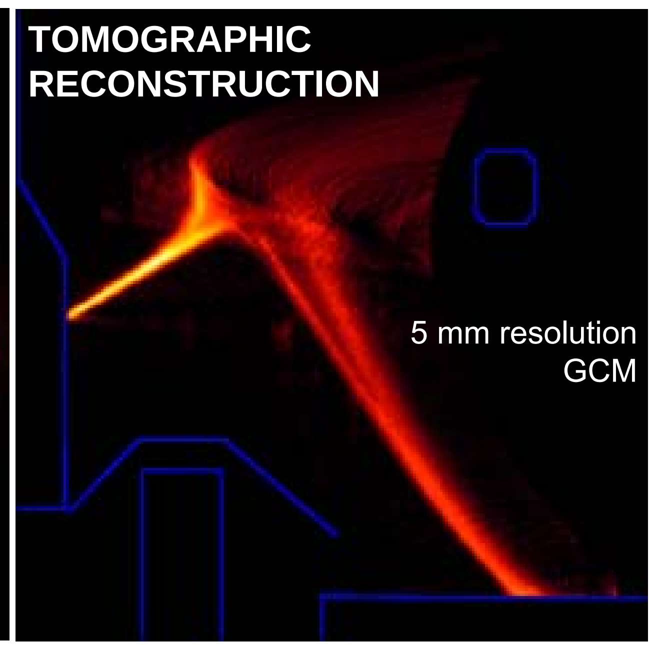


(a) (b)

DIVCAM

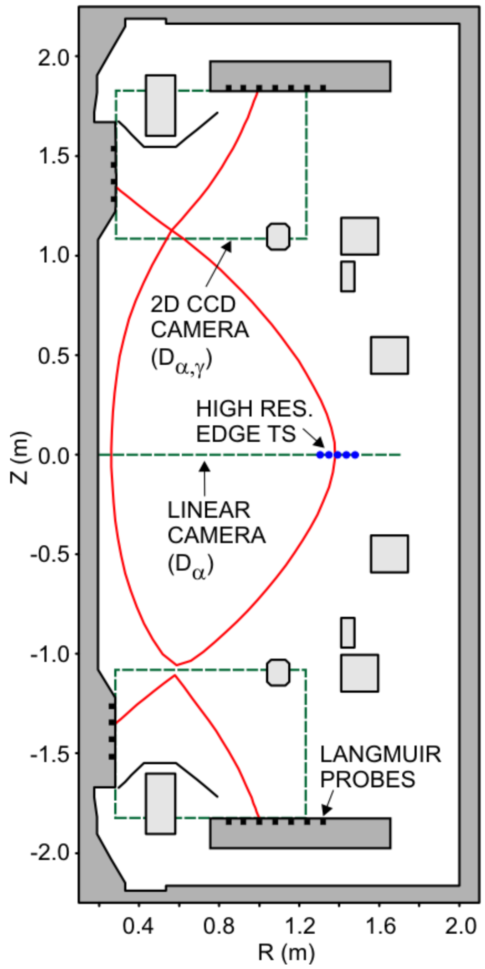
- Filtered divertor CCD camera for benchmarking boundary transport models (beam splitter allows simultaneous measurement at two wavelengths)
  - carbon filters: CI, CII, CIII
  - deuterium: Balmer lines for transitions n = 3,4,5,6 $\rightarrow$ 2
  - molecular emission: C-D, C-C, D-D (sub-sampling of band)
  - injected impurities: He, Ar, Sn, Al
- Image data are integrated along the diagnostic lines-of-sight, but want 2D emission in the poloidal plane for quantitative comparisons $\rightarrow$ "pixel-based" tomographic inversion
  - custom ray tracing and image processing software has been developed

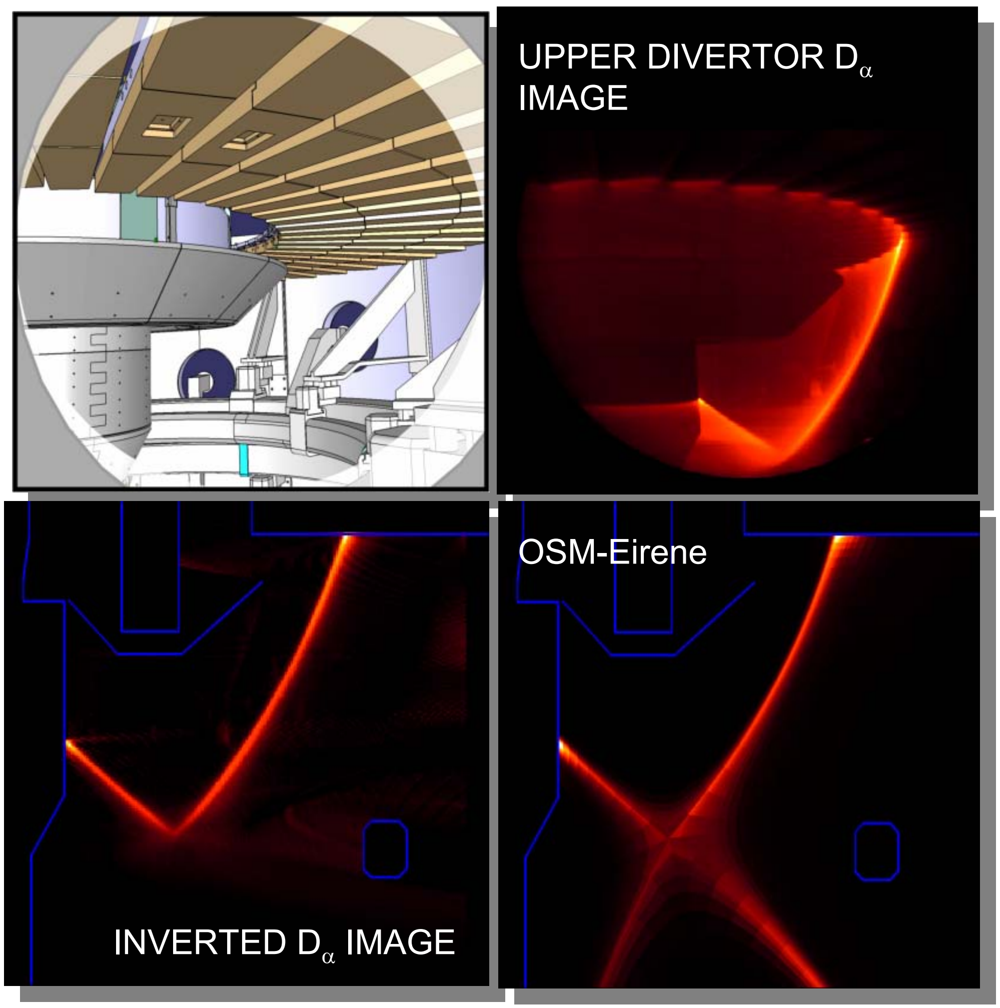




Core fuelling profile

- The extrapolation of pedestal particle transport models to next-step devices requires the accurate determination of the core ionisation profile





Core fuelling profile

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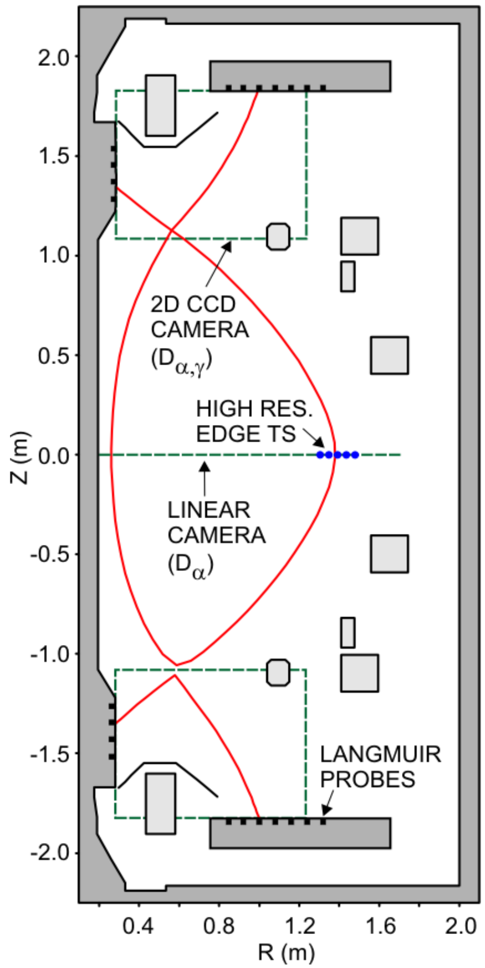
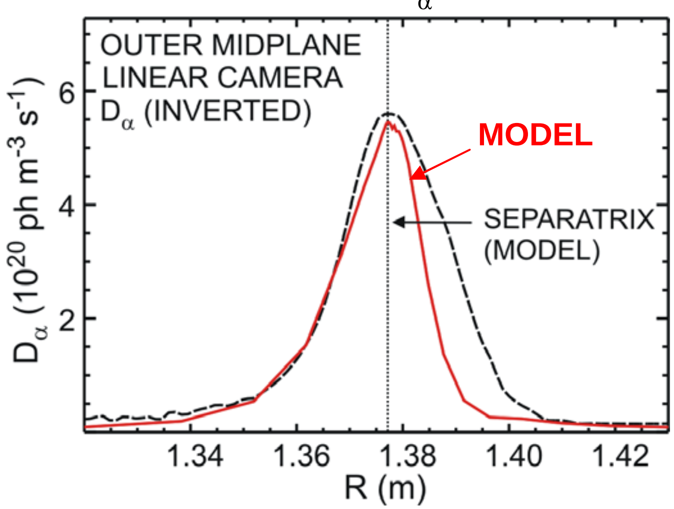


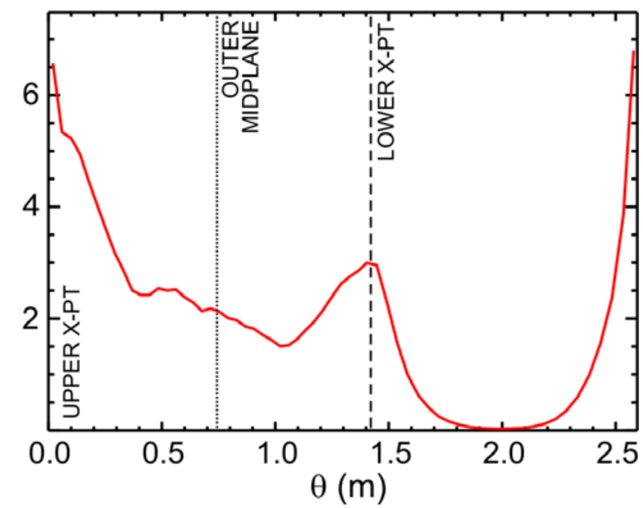
❑ Interpretive modeling with the OSM-EIRENE boundary plasma code can be used to calculate core fuelling, and has the advantage of utilizing a large amount of experimental data as input to the simulation

- D_α measurements (1D, 2D) in the divertor and upstream
- Langmuir probes in the divertor
- outer mid-plane high resolution Thomson scattering

QUANTITATIVE COMPARISON WITH MIDPLANE D_α



POLOIDAL DISTRIBUTION OF CORE IONISATION



Helium line ratio data

Many basic features of the boundary plasma still poorly understood

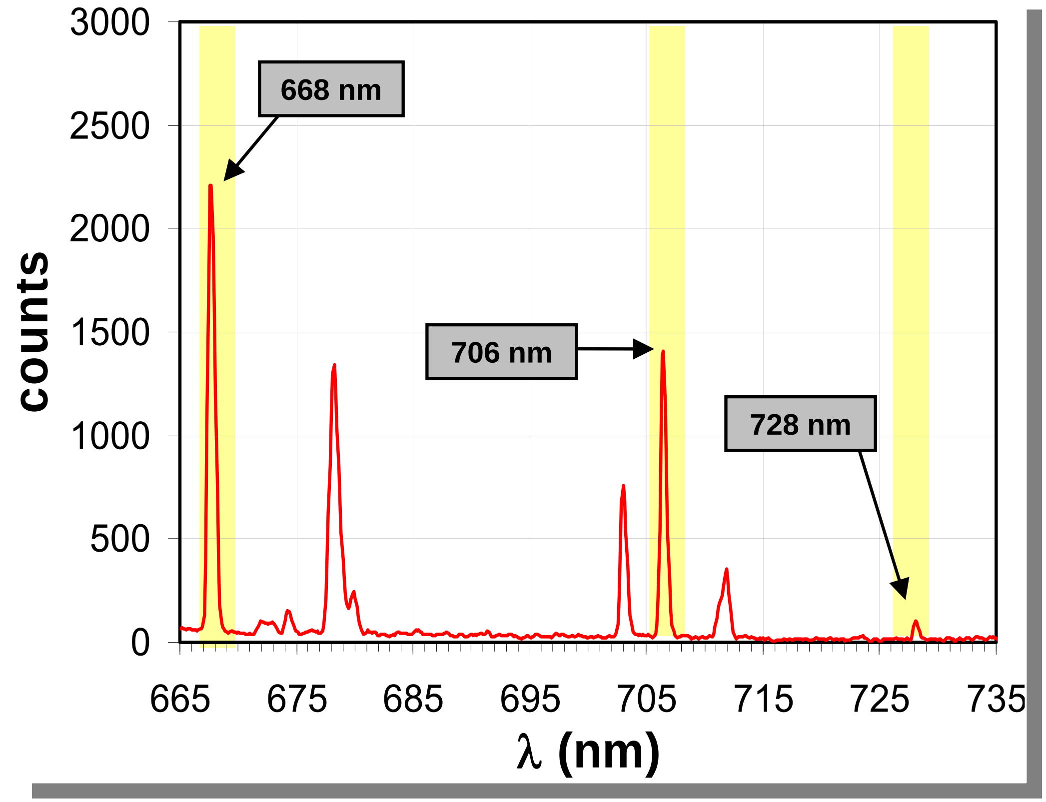
– complex 2D structure but (usually) only <u>point</u> measurements available
– very limited $v_{||}$, T_i data
– impurities important

He I 706 nm / 728 nm

T_e ($5 < T_e < 40$ eV)

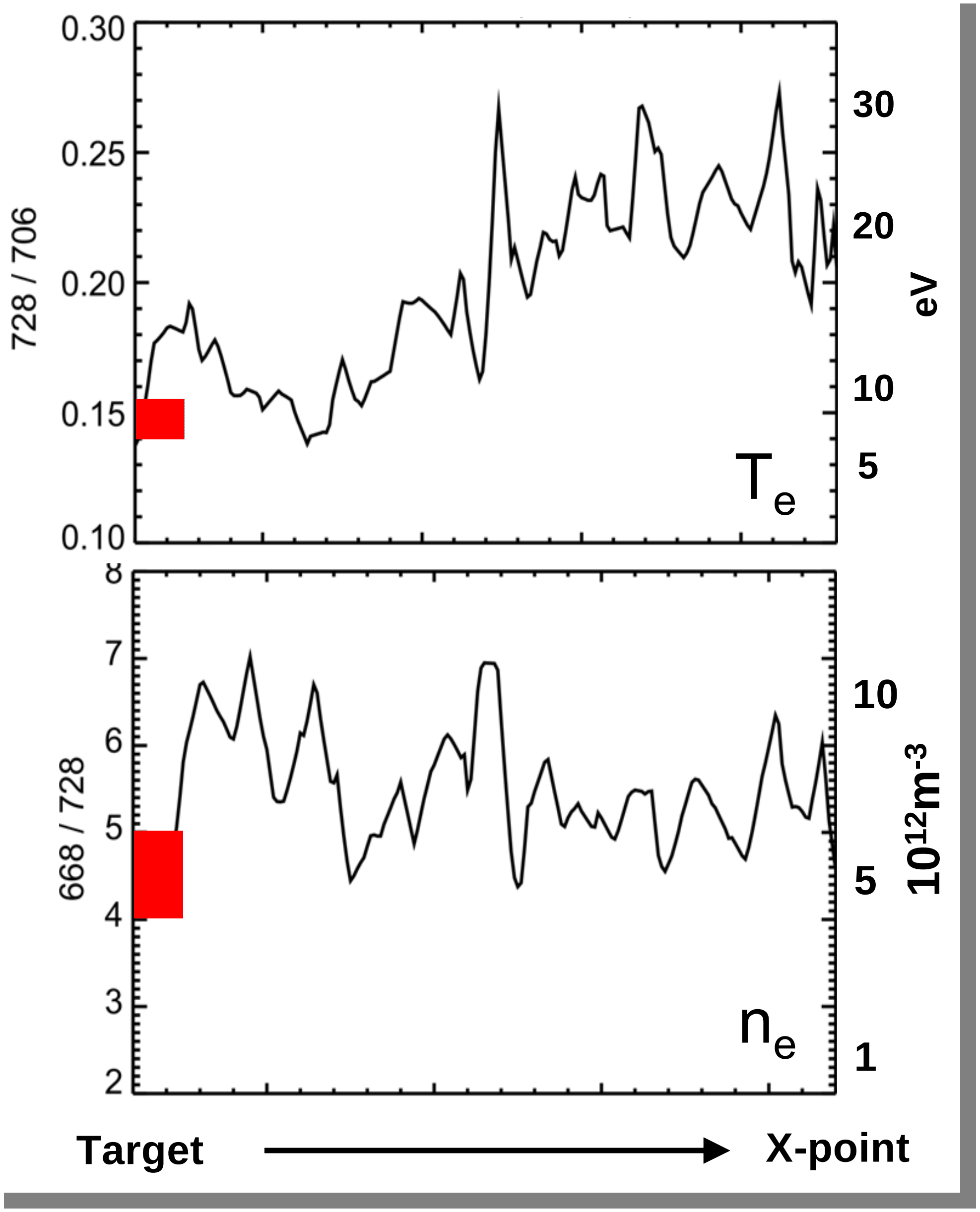
He I 668 nm / 728 nm

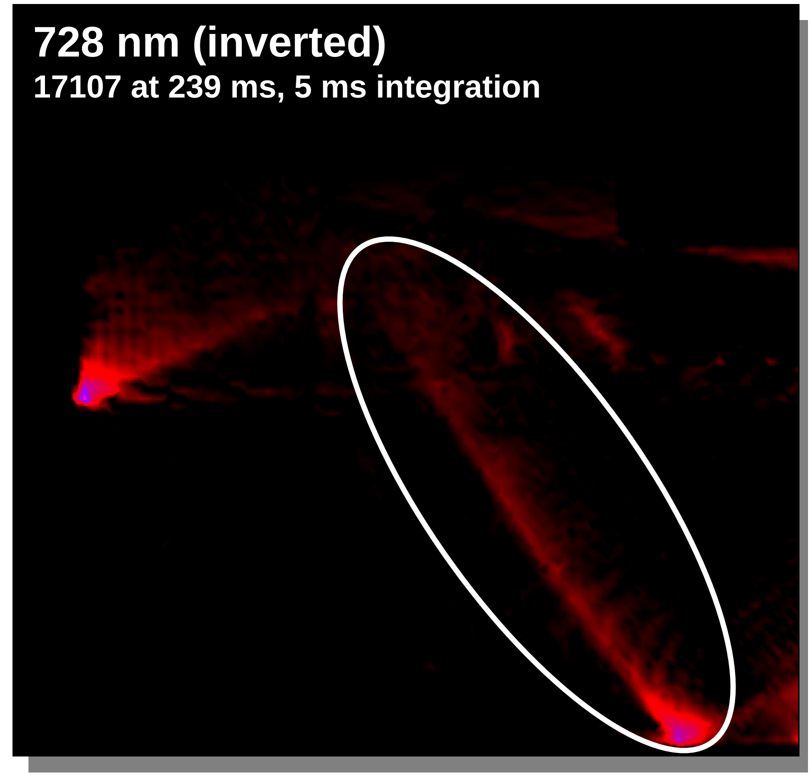
n_e (10^{18}–10^{19} m^{-3})



Valid for limited range of n_e, T_e
<u>but</u> boundary plasma relevant

Helium line ratio data





Target values agree with Langmuir probes

Integration into OSM-EIRENE ongoing

Diamond tests

Evaluation of <u>diamond</u> as a candidate plasma facing material

- no chemical sputtering
- very high thermal conductivity
- (in-situ repair, eventually…)

STRENGTH

- physical sputtering from 1 keV D+ same as CFC
- insulator (normally) → *arcing*
- very low thermal expansion → *delamination*

WEAKNESS

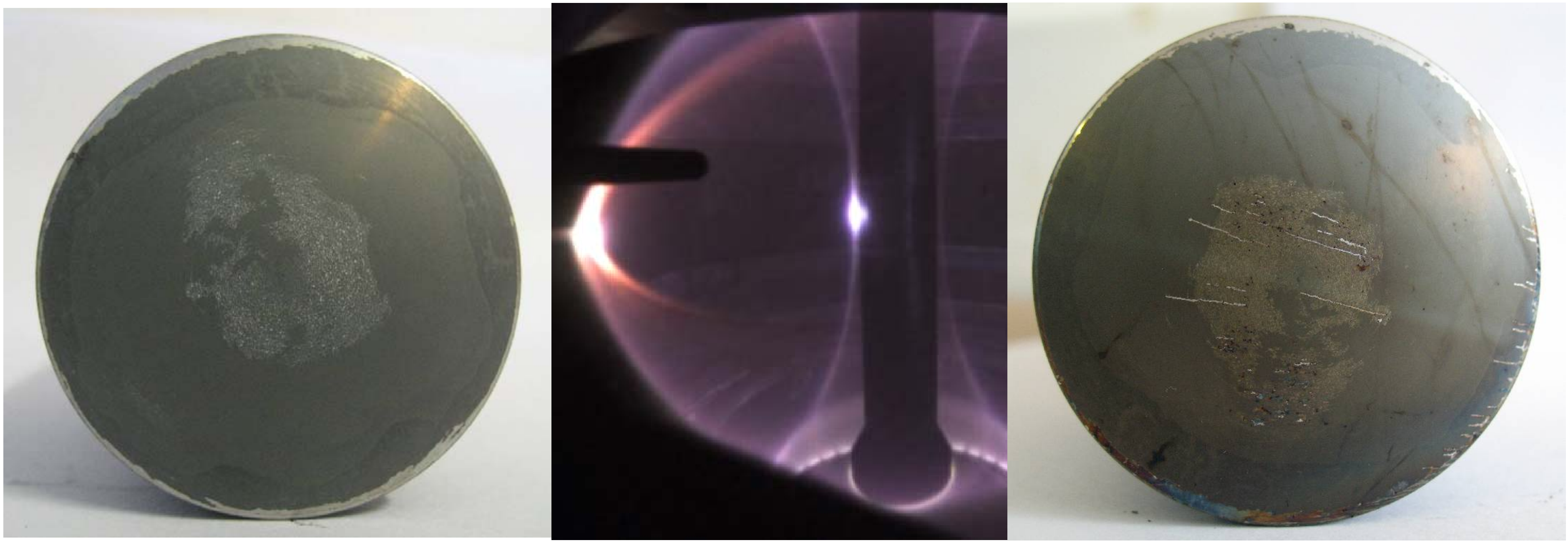
"Putting next generation fusion materials on the fast track"

- 3 year, €1M university project
- diamond films produced by chemical vapour deposition (CVD)

…Initial tests of CVD diamond as a plasma facing material

- Preliminary physics studies underway on the MAST tokamak
  - ~1 micron thick film on molybdenum: microwave and hot filament samples tested
  - ~1 second of plasma exposure at ITER-relevant flux: 5×10^{23} m^{-2} s^{-1}, 50 eV
- Film notably modified by the plasma but no catastrophic failure
- In collaboration with Heriot-Watt University and University College London

Pre-exposure | 18509 at 204 ms | Post-exposure



- Long term sample installed in MAST divertor for 2008 campaign

Concluding remarks

There are many recent and planned new technical developments on MAST which greatly enhance our capabilities

The MAST/NSTX physics programmes exhibit much synergy and complementarity which strengthens both programmes

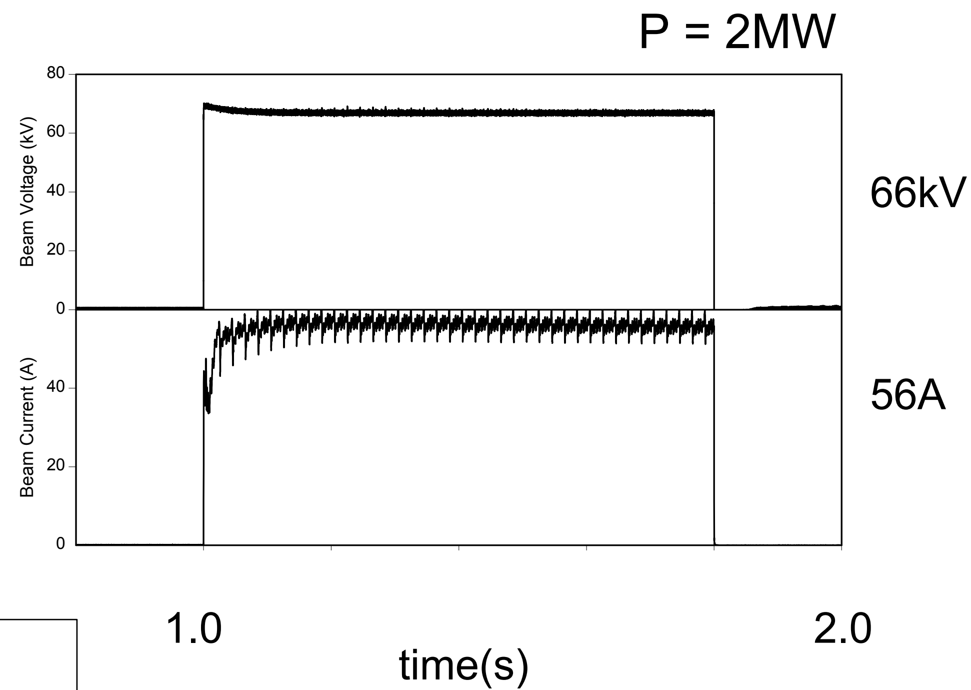
Major upgrades to MAST are planned: new centre column (increased flux) with chilled coolant; new PF coils and power supplies; higher performance TF, more closed, cryo-pumped divertor; increased beam power with off-axis and cntr capability, high power EBW, continuous pellet fuelling…

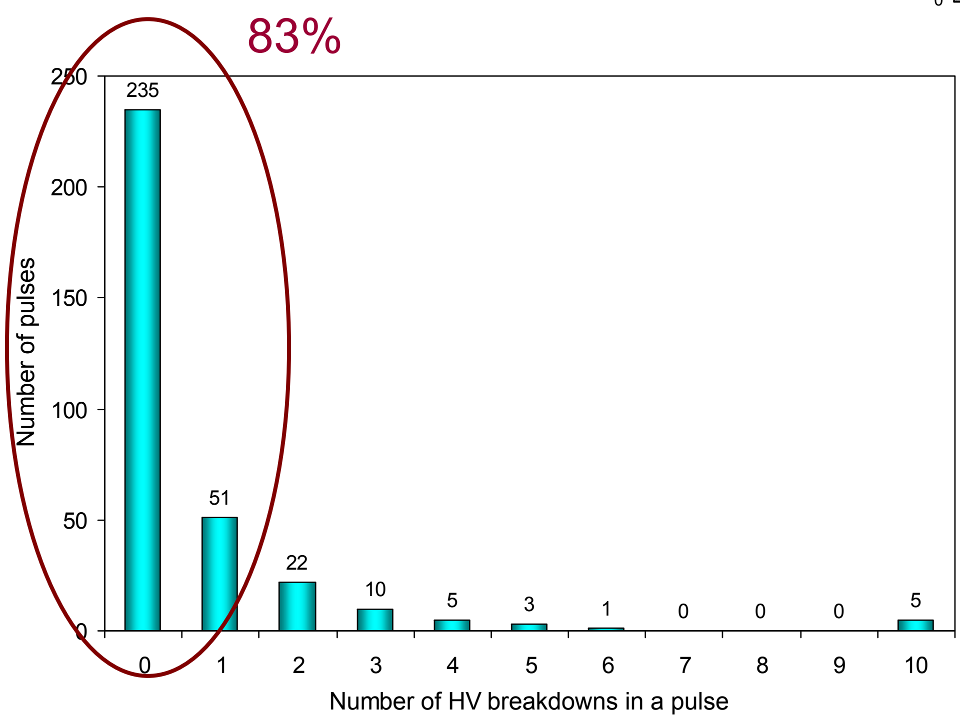
In 2008 there will be a major EU facilities review. Implementation of our upgrade plans is dependent on the outcome of that review

Additional slides

MAST PINI performance 2007

- Record power output from this type of PINI:
  - 2.0MW (ASYNC)
  - 1.9MW (SYNC)
- Total NBI power, energy:
  - 4MW, 2MJ (ASYNC)
  - 3.8 MW, 1.65MJ (SYNC)
- Max. pulse length 2.9s (ASYNC)





- 83% of all pulses injected in 2007 were either breakdown-free or with only one HV breakdown.
- Highly reproducible beam parameters – standard deviation of main beam parameters recorded over long operational periods is < 2%

MAST PINI performance

- Record power output from this type of PINI:
  - 2.0MW (ASYNC)
  - 1.9MW (SYNC)
- Total NBI power, energy:
  - 4MW, 2MJ (ASYNC)
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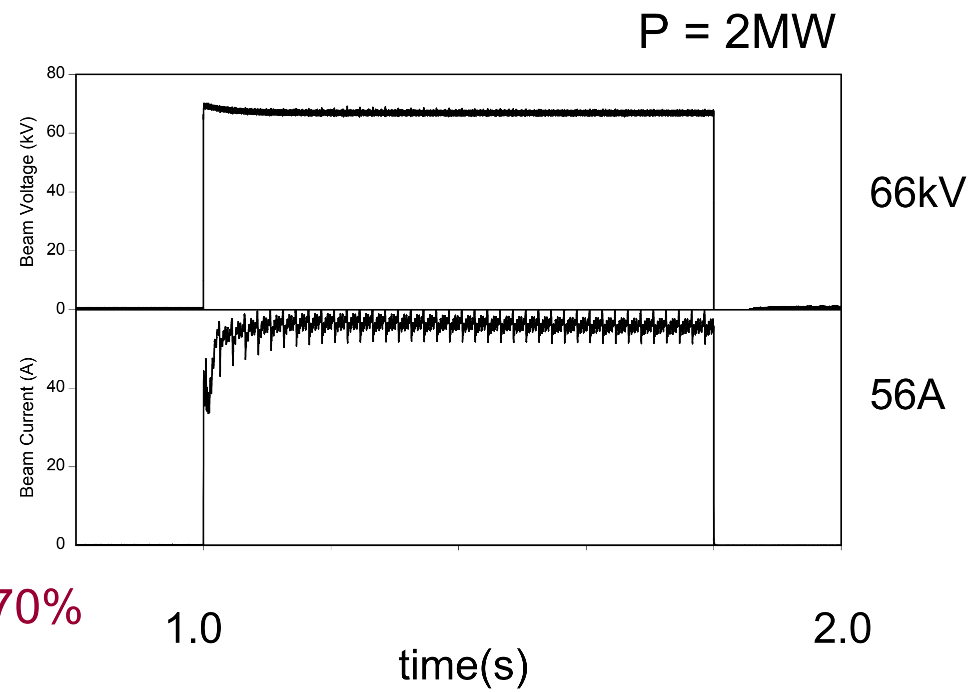

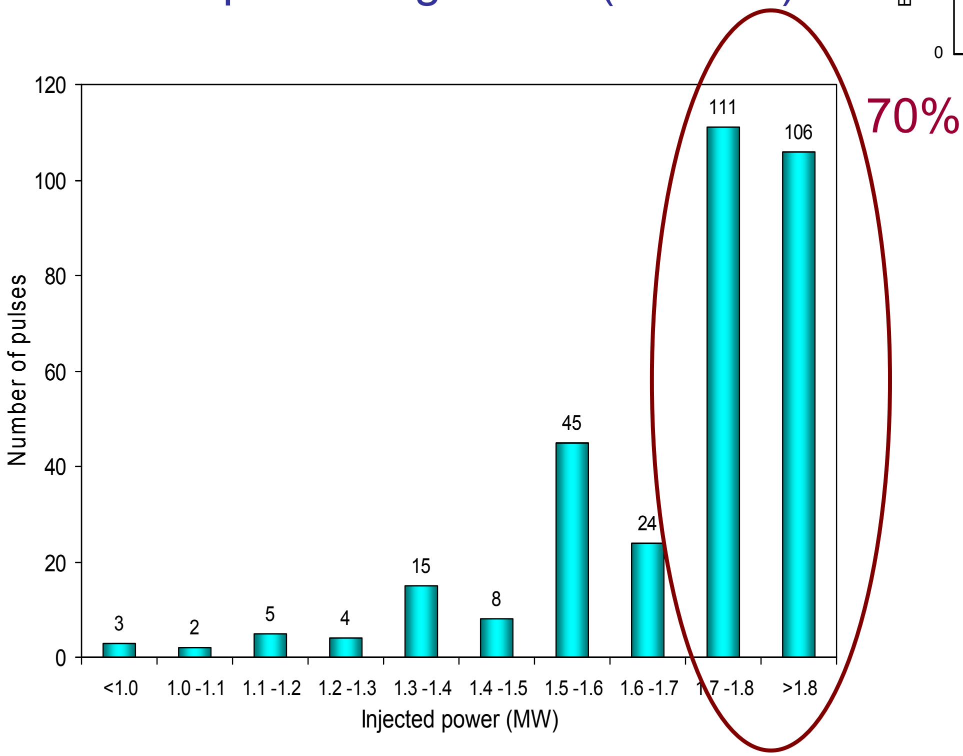

- 70% of all PINI pulses injected in 2007 were above 1.7MW

NBI upgrade – next steps

- Installation and commissioning of the second PINI.
- Beam modulation with fixed or variable mark/space ratio.
- Power variation during beam pulse, by varying beam current at fixed beam voltage.
- Real-time feedback control.

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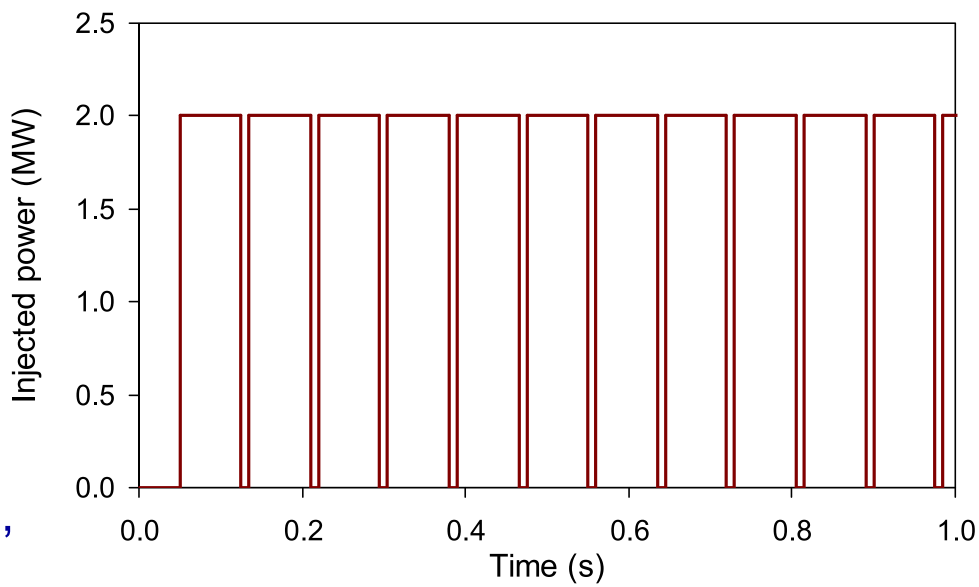

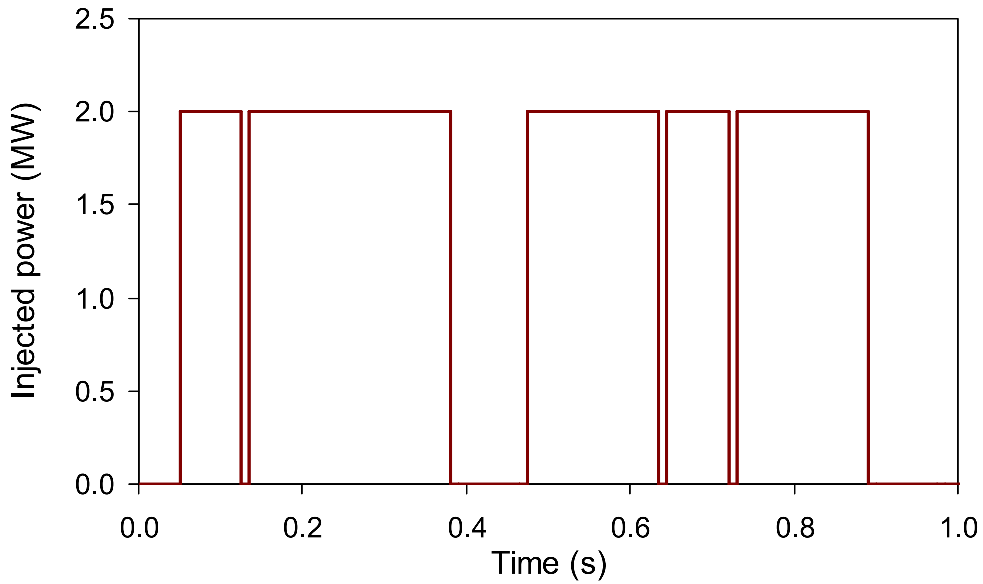

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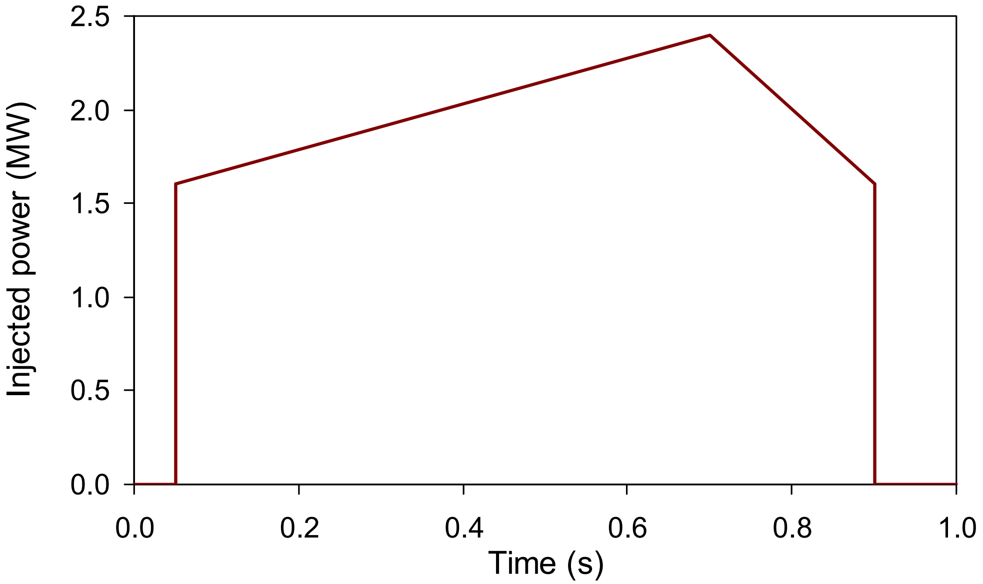
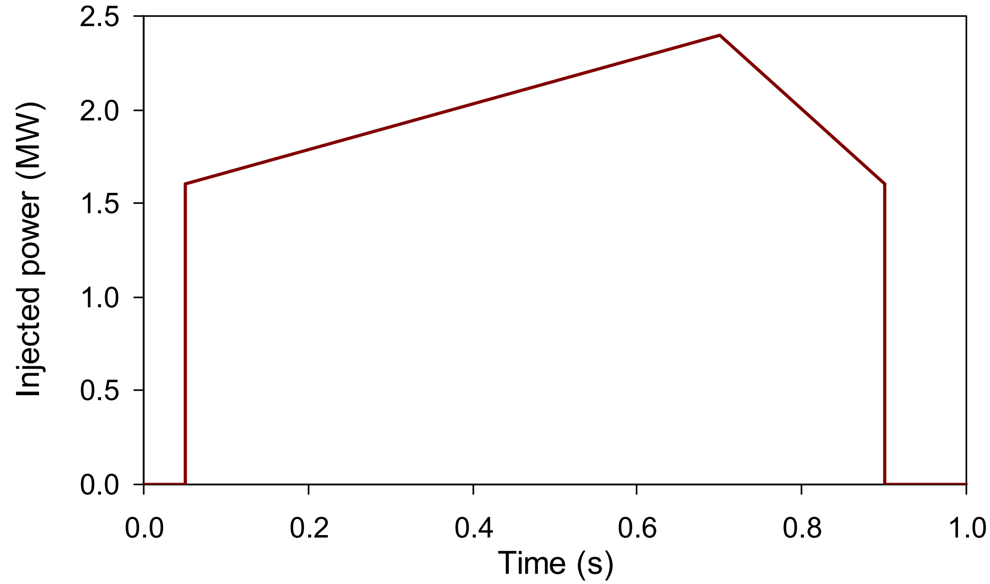
- Beam modulation with fixed or variable mark/space ratio.
- Power variation during beam pulse, by varying beam current at fixed beam voltage.



- Real-time feedback control.

NBI upgrade – next steps

- Installation and commissioning of the second PINI.
- Beam modulation with fixed or variable mark/space ratio.
- Power variation during beam pulse, by varying beam current at fixed beam voltage.



- Real-time feedback control.

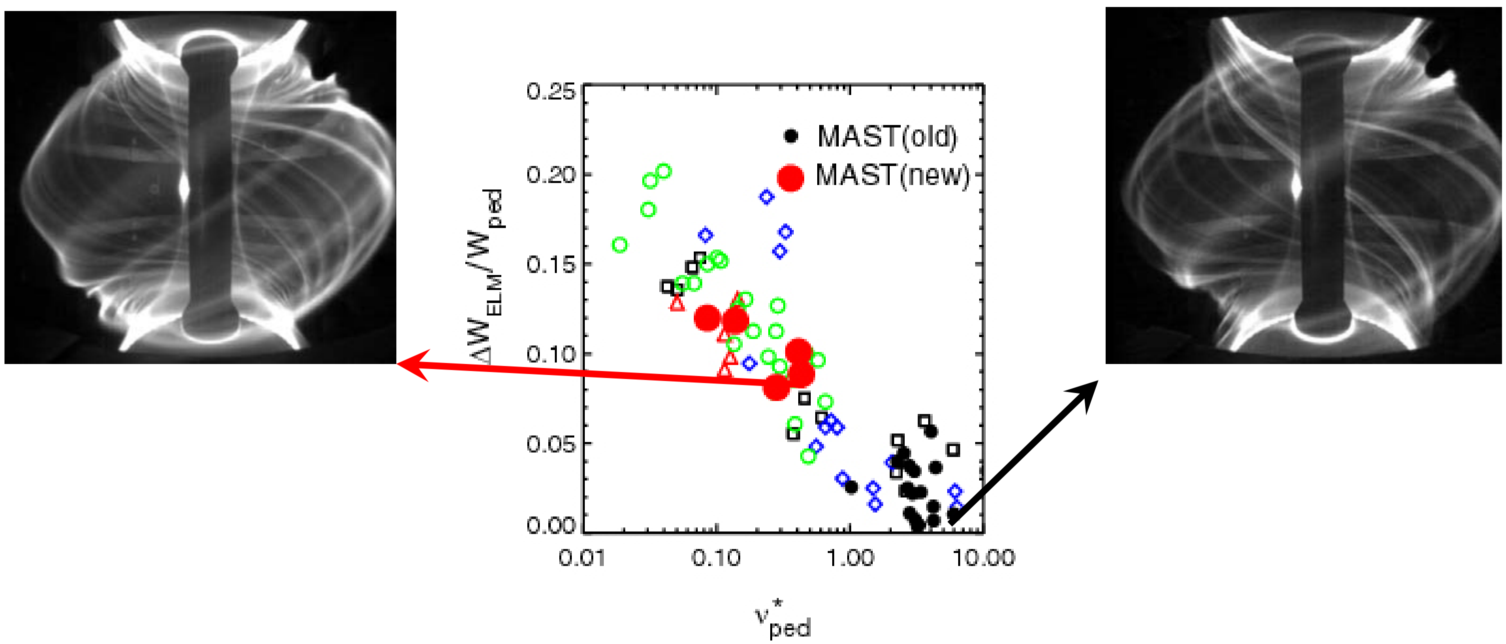
ELM filaments in MAST

- Filaments remain close to the LCFS for 50 - 200 μs - during this time they enhance transport into the SOL. Dominant loss mechanism ⇒ parallel transport.

- Transport to wall through radial propagation of filaments

- At the time of detachment each filament contains up to 2.5 % ΔW_{ELM}

Comparison of type I ELMs at different ν* on MAST



Very little difference in the size (~5-8 cm) or number of filaments (10-18)

International collaborations - technical

CXRS
(DCU, Ireland)

BES (HAS, Hungary)

MSE (VR Sweden, DCU)

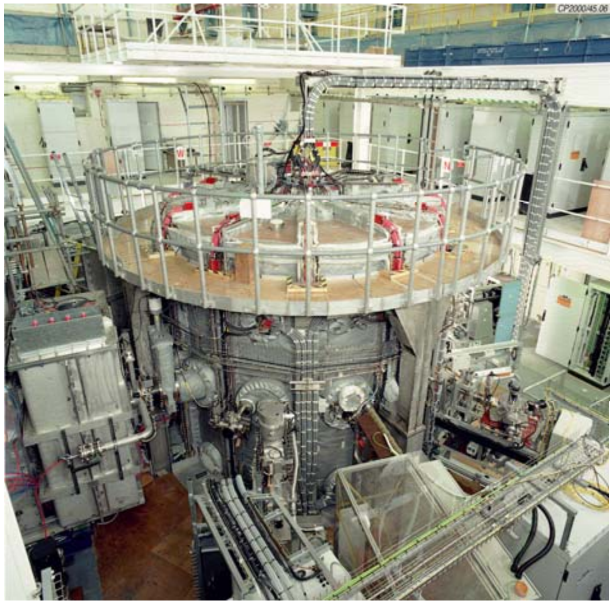
Reflectometry
(IST, Portugal)

Bolometry
(IPP Garching)

NPA
(PPPL, IPP Greifswald)

SXR
(IPPLM, Poland)

MAST



Thomson scattering
(DCU, Ireland)

ELM mitigation coils
(FZJ, CEA, GA)

Pellet injection
(HAS, CEA, ORNL, ENEA, FOM)

NBI
(ORNL)

EBW
(Ioffe, PPPL, ORNL, CRPP, IPP.CR)

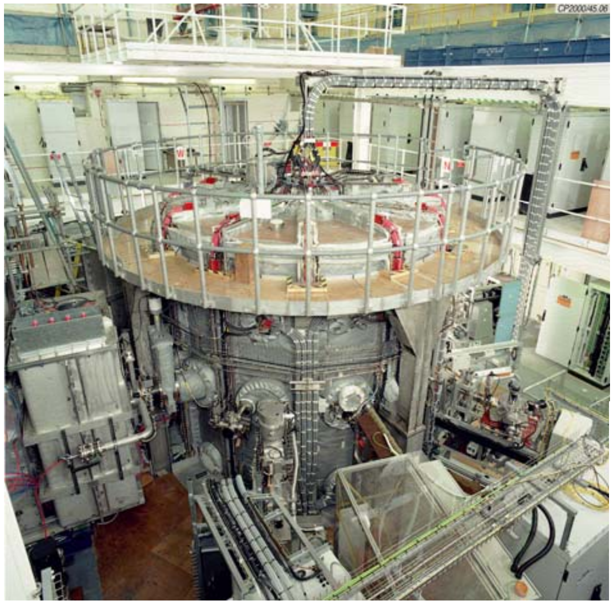
Plasma control
(GA, CRPP)

UKAEA Fusion Working in Europe

International collaborations - physics

MAST

Start-up/reconnection
(ENEA, U. Tokyo)



Confinement, transport & turbulence
(PPPL, GA)

ELM physics/control
(IPP, FZJ, CEA, GA, PPPL, MIT)

MHD/fast particle instabilities
(IPP, PPPL)

Pedestal physics
(IPP, PPPL, GA)

Exhaust physics
(EU PWI Task Force, LLNL, MIT, U. Toronto, St. Petersburg Tech. Univ.)

EBW studies
(IPP.CR, Ioffe, PPPL, CRPP, ORNL)

UKAEA Fusion Working in Europe

MAST - UK university collaboration

- York – instabilities (ELMs, NTMs, Alfven eigenmodes), transport & turbulence, edge physics, diagnostic development (Thomson scattering)
- Warwick – fast particle driven instabilities, transport studies, edge turbulence
- Imperial College – plasma control & disruptions, instabilities (ELMs, ..), transport studies, Doppler spectroscopy, edge physics
- Strathclyde – atomic physics, material erosion and transport of heavy impurities
- Manchester – edge physics
- Sheffield – turbulence (zonal flows)
- UCL – advanced plasma facing materials
- Heriot-Watt – advanced plasma facing materials
- Glasgow – impurity transport simulations
- Edinburgh – turbulence code development (CENTORI)
- QUB – atomic physics & spectroscopy
- Cranfield, Surrey, Univ. of the West of England – related engineering projects