The structure of ELMS and the distribution of transient power loads in MAST

MAST

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EURATOM / UKAEA Fusion Association

- The filamentary structure of ELMs
- The effect of rotation
- The radial expansion of ELMs
- Filaments during disruptions

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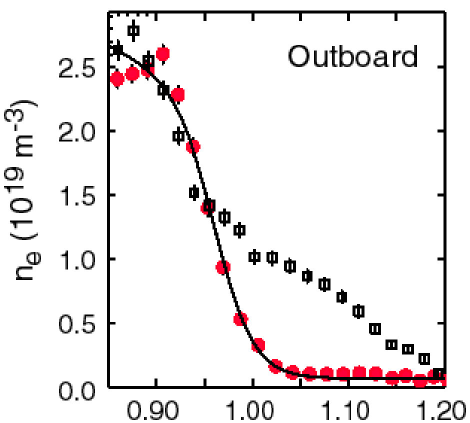
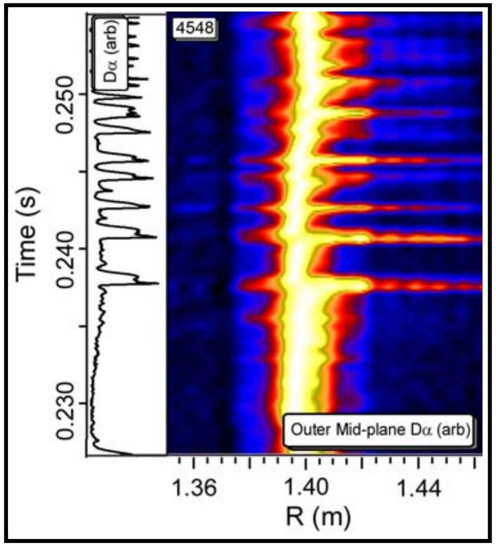
First evidence for radial efflux

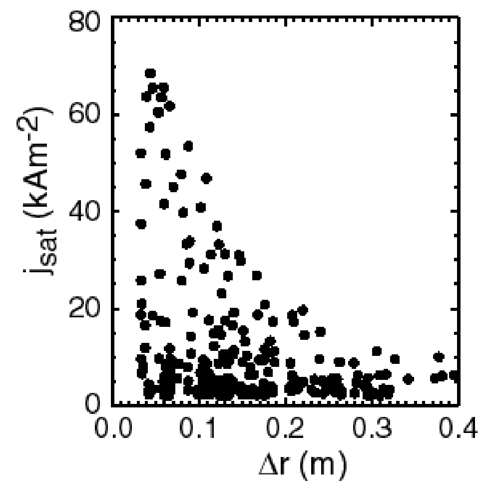
TS profiles obtained near ELM peak show the formation of a broad n_e tail only on the outboard side



ELMs show D_α emission well beyond outboard separatrix



Large particle flux (J_{SAT}) to outboard mid-plane probe during ELM



First evidence for ELM structure

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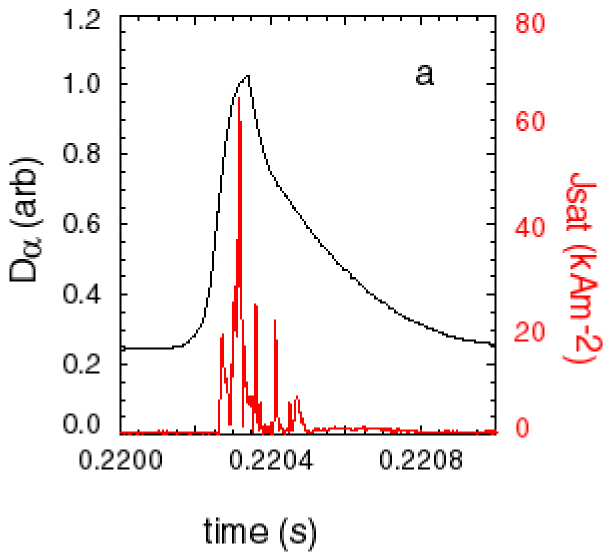
$V_{\phi}^{ped} \sim 15\ kms^{-1}$



When the Reciprocating Probe is close to the plasma edge - structure is observed in the J_{sat} signal

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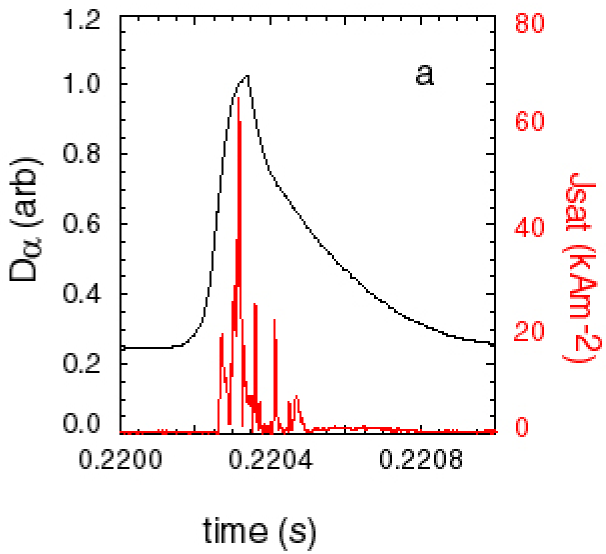
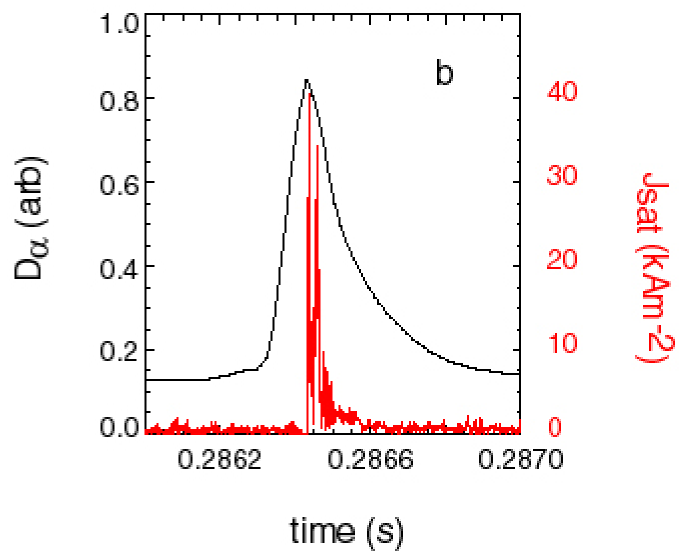
The effect of toroidal rotation

V_ϕ^{ped}~15 kms^{-1}

V_ϕ^{ped}~25 kms^{-1}



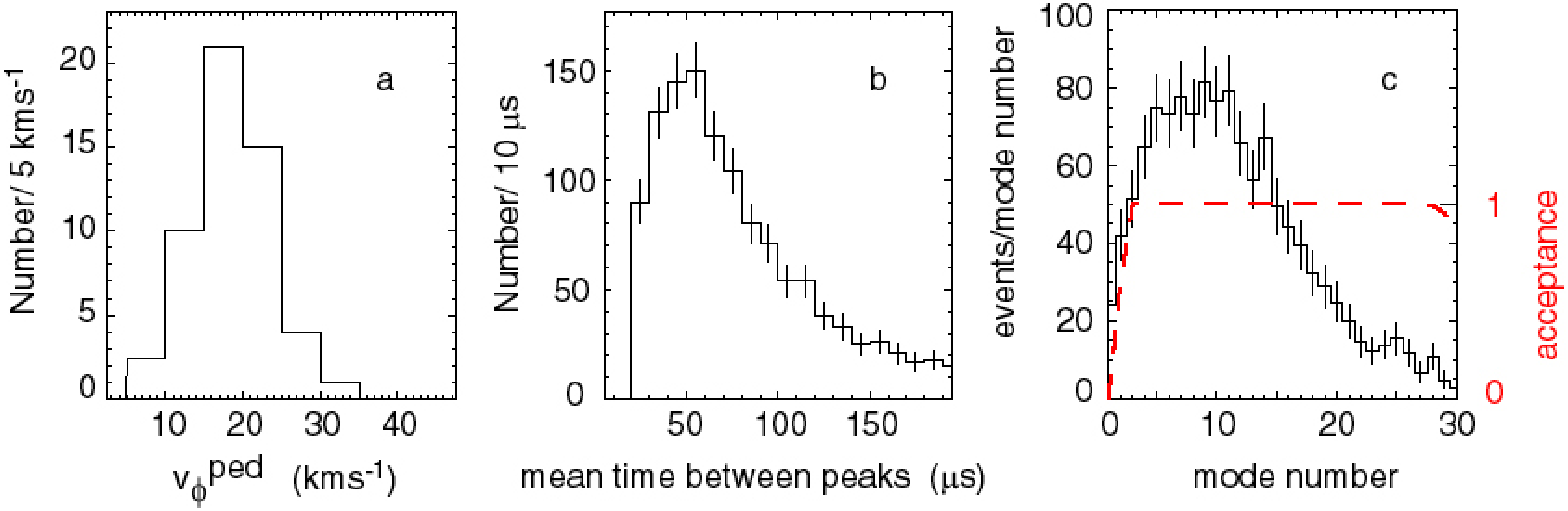


$$Mode\,number = \frac{2\pi R_{outer}}{V_{ped}\Delta t}$$

n~12

n~18

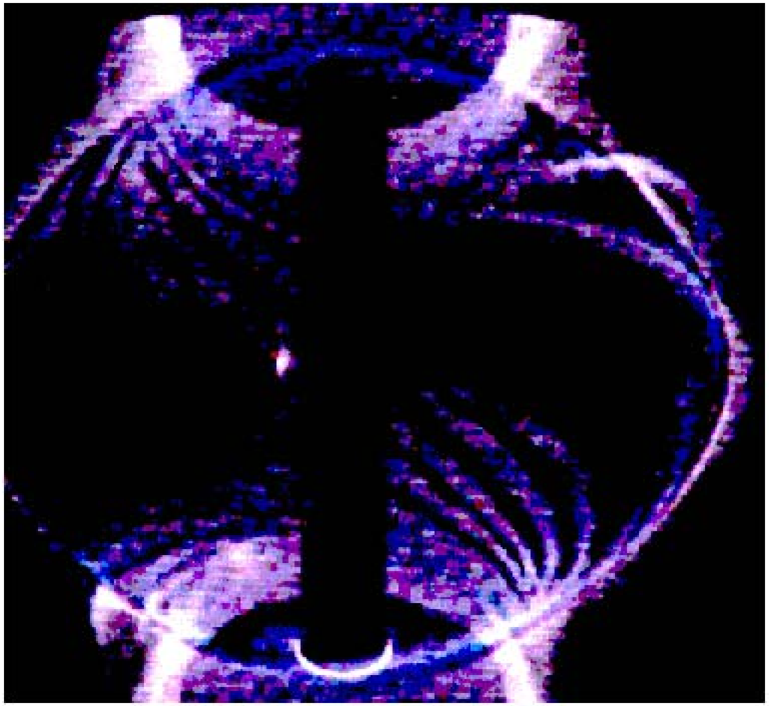
The effect of rotation - toroidal mode number



Range of ELMs give mean mode number ~ 10

Consistent with most unstable modes typically predicted by linear theory (ELITE)

ELM spatial structure (experiment)



Filaments are observed which are consistent with the structures expected from the theory of the non-linear evolution of ballooning modes [Wilson and Cowley]

ELM spatial structure (experiment+theory)

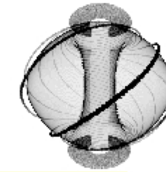
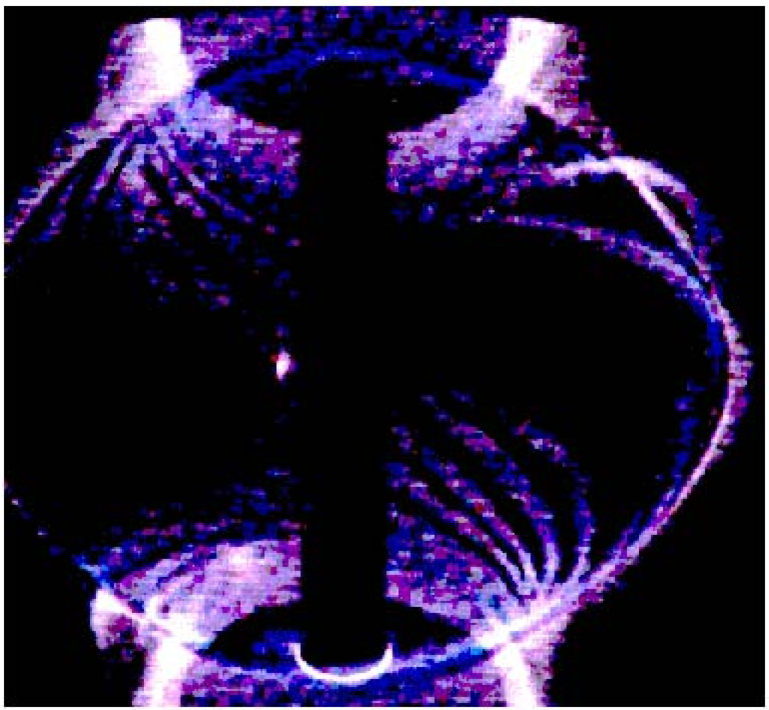
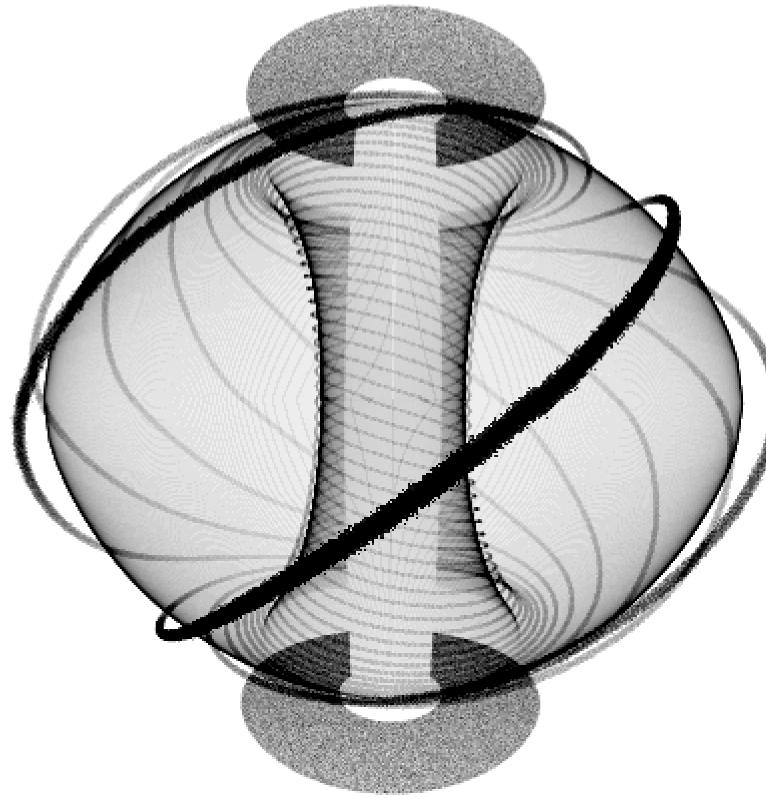


Image simulation of the expected structure with q_{95}=4 and n=10

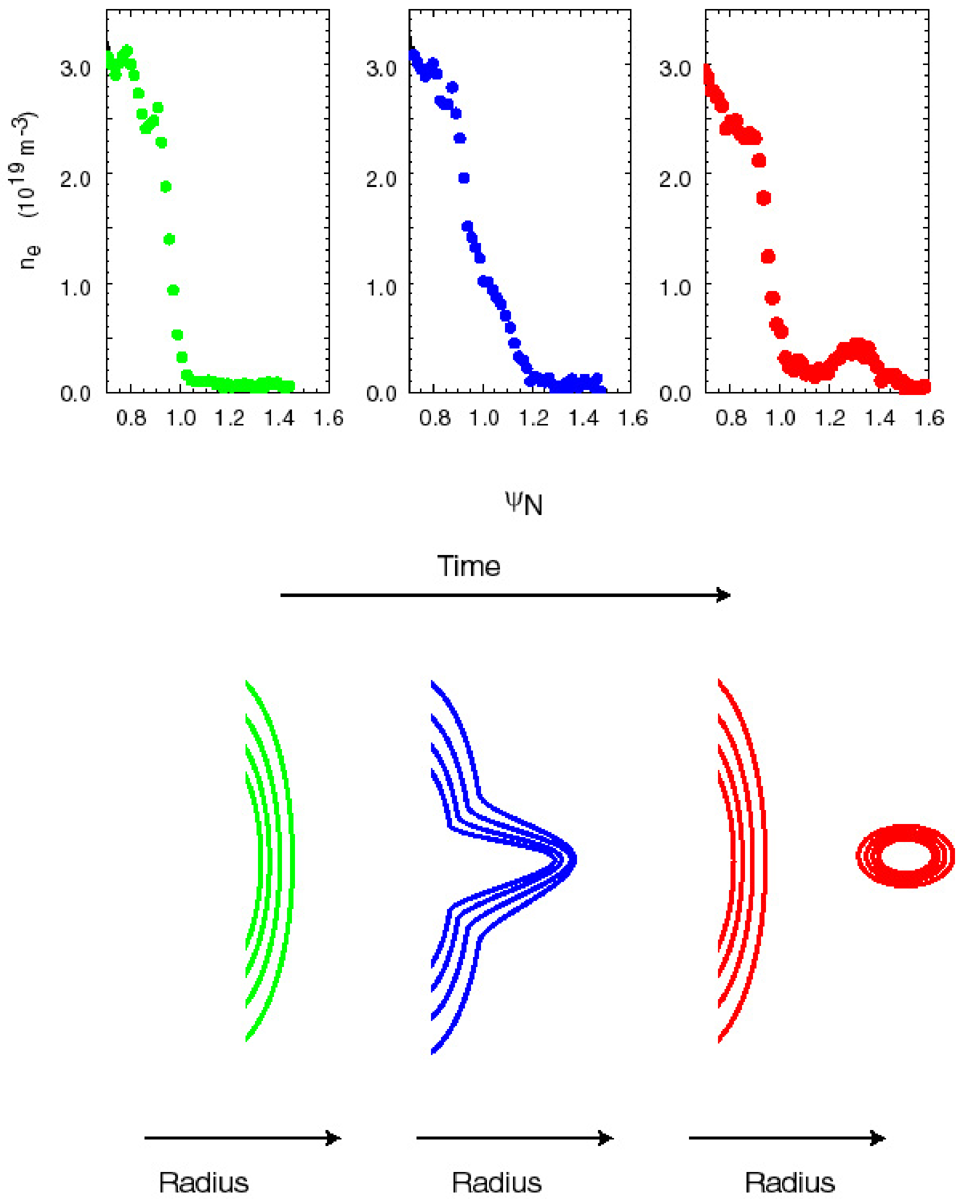


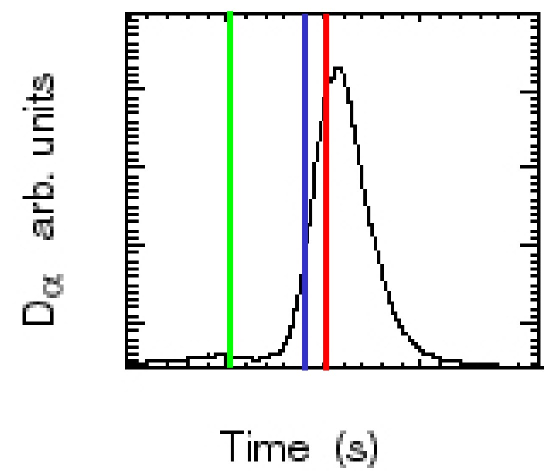


The spatial and temporal evolution of an ELM

Experiment

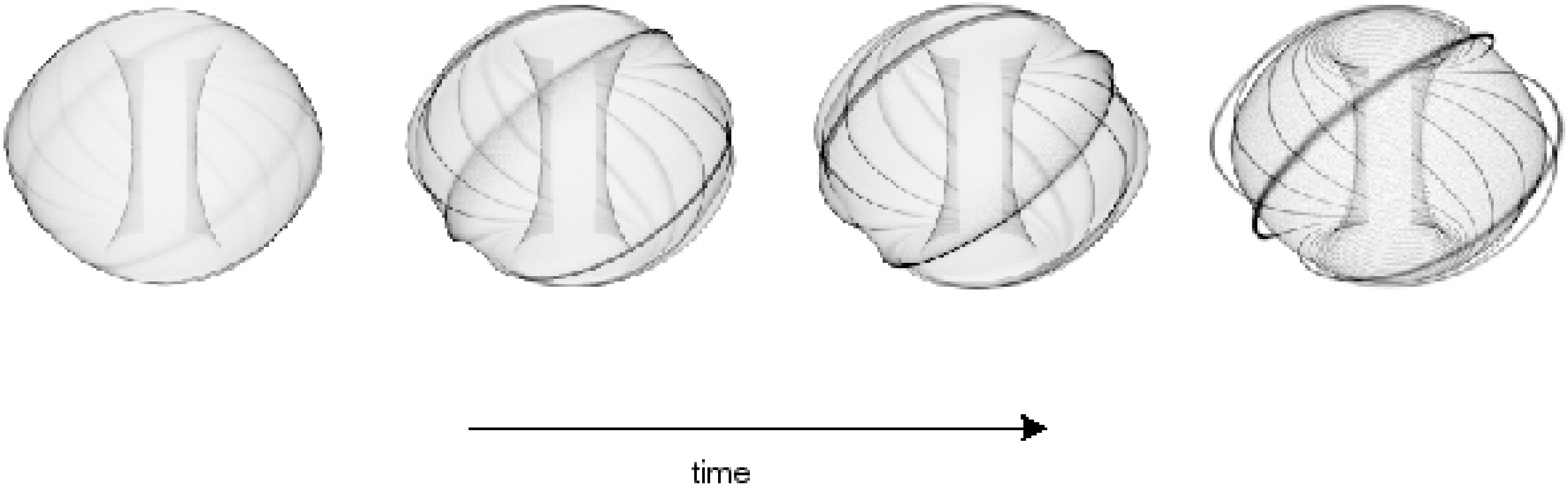
Theory





The spatial and temporal evolution of an ELM

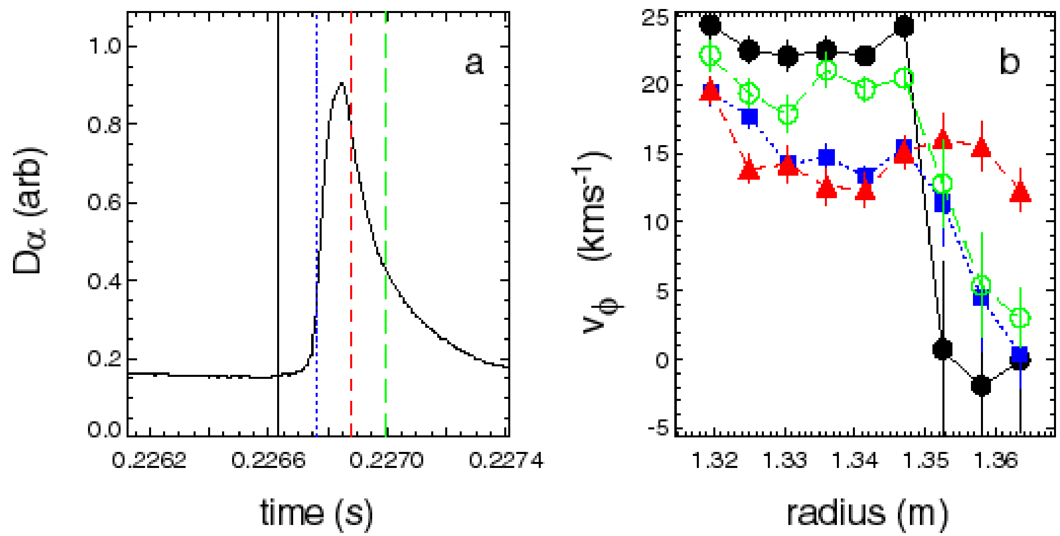
- simulated



The effect of rotation - edge velocity shear

Impurity velocity using visible Doppler spectroscopy

125 μs time resolution



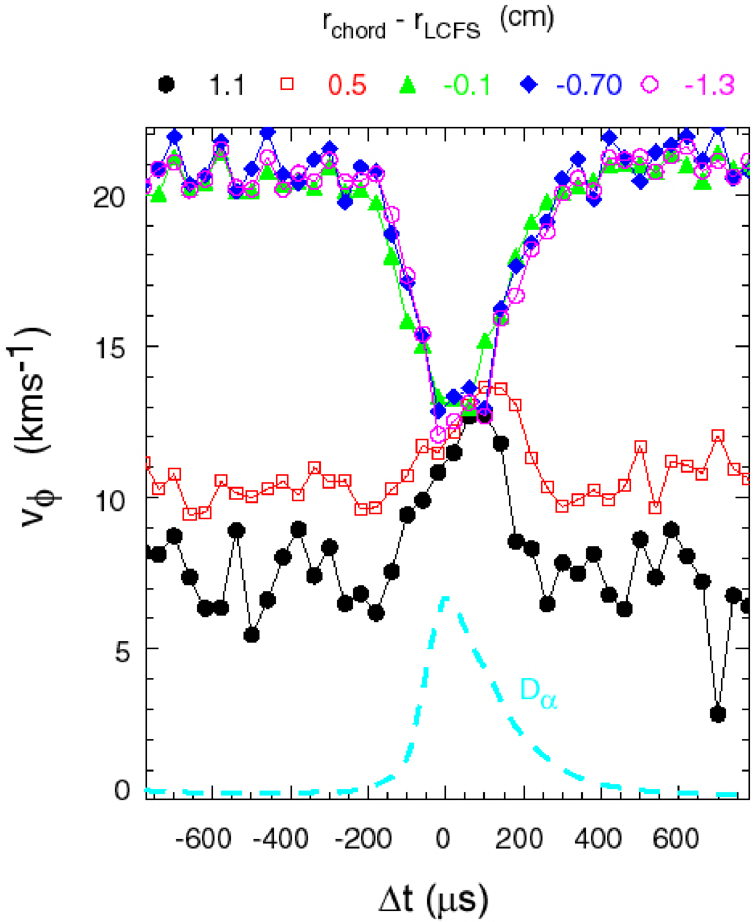
Edge velocity shear before ELM

shear greatly reduced at ELM peak

then quickly recovers

The effect of rotation - edge velocity shear

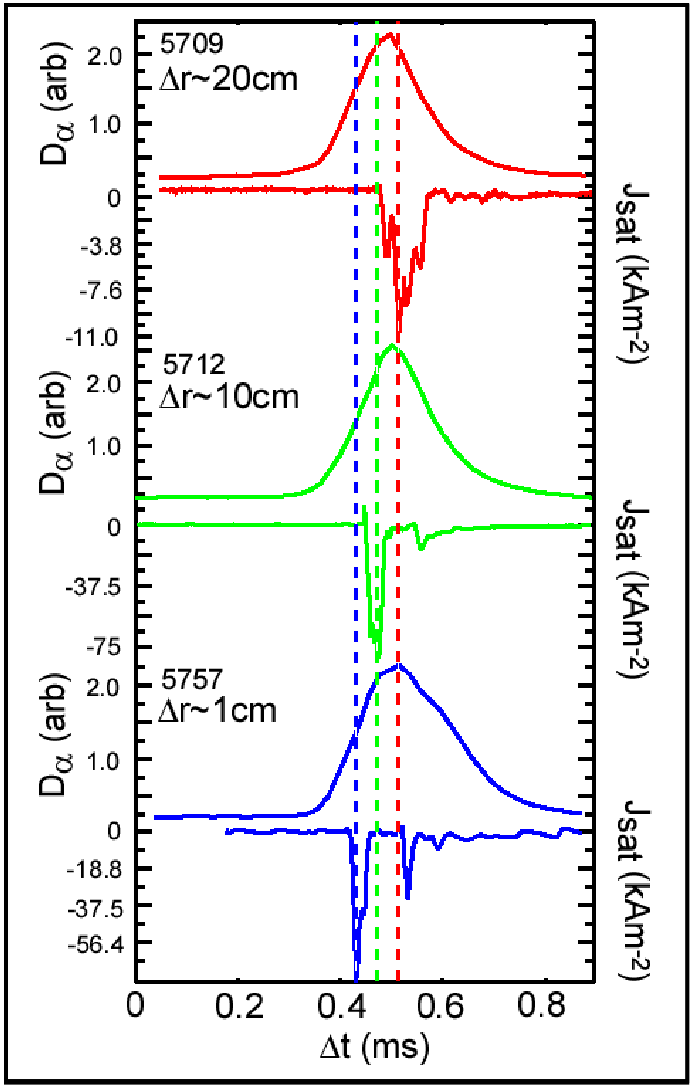
Using a box-car technique and averaging over several ELMs

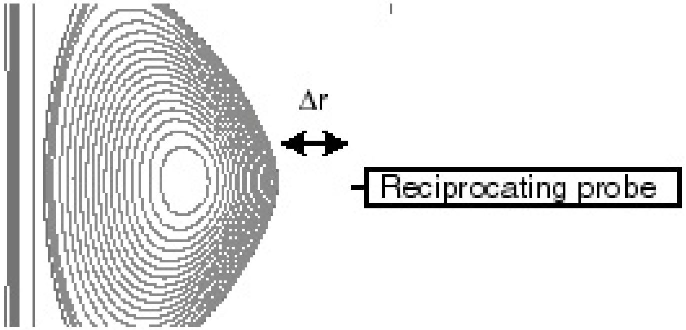


Edge velocity shear greatly reduced at ELM peak

A necessary requirement if the filaments are to propagate radially

The radial expansion of the filament

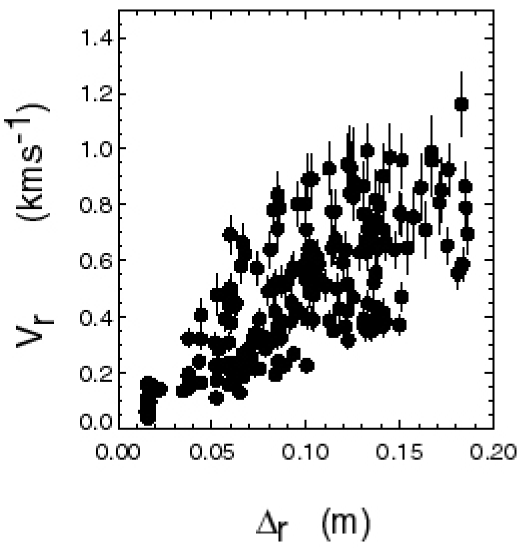




- The particle flux (Jsat) delayed from divertor D_α - increases with distance outside the separatrix (Δ_r)

- Estimated radial velocity V_r~1 km/s

The radial expansion of the filament



The time delay measured has two components
the true radial expansion velocity and
the delay due to the finite toroidal extent of the localised filaments

The true radial expansion velocity can be estimated using a simulation

Delay depends on radial and toroidal velocity

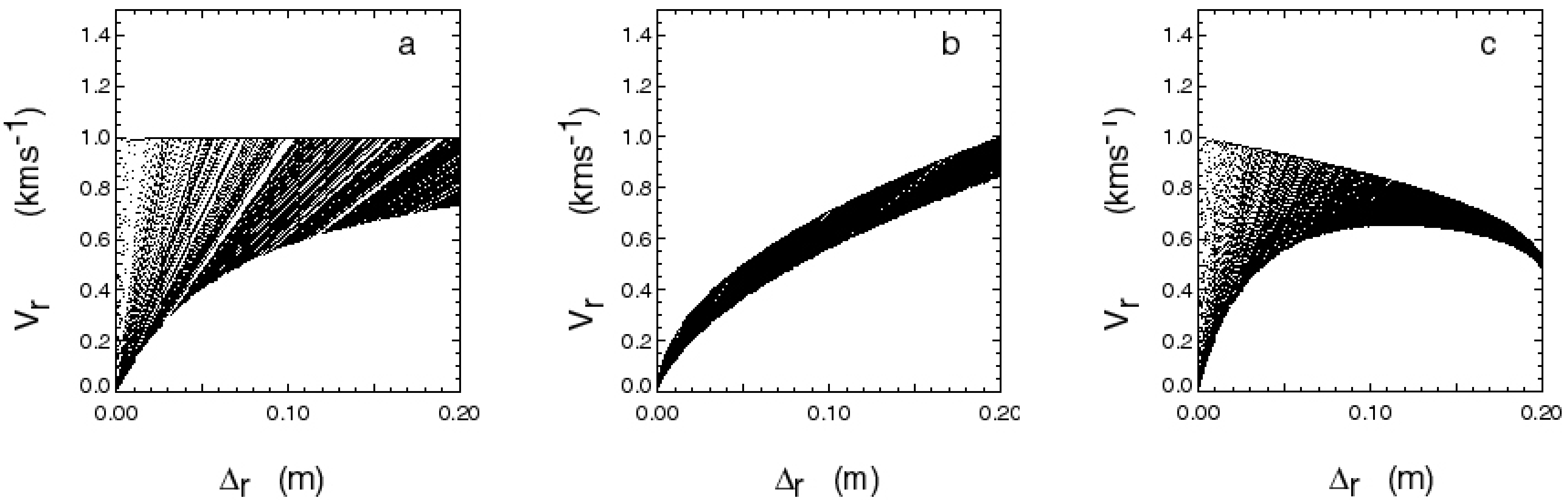
The radial expansion of the filament

Monte Carlo simulation of calculated V_r as a function of Δ_r for:

Constant velocity = $1 kms^{-1}$

Constant acceleration = $1x10^7\ ms^{-2}$

Constant deceleration = $2.5x10^6\ ms^{-2}$



Data most consistent with an accelerating filament

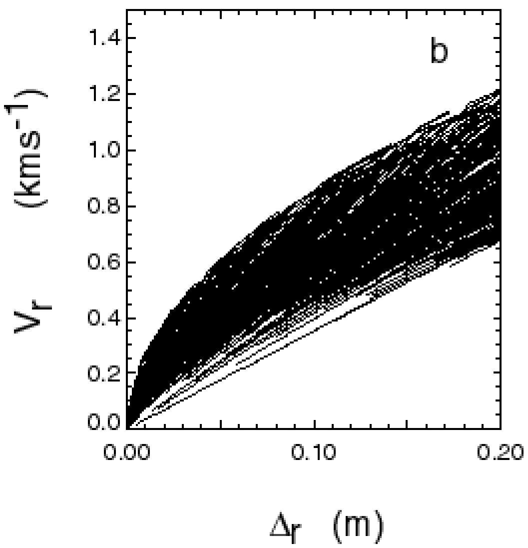
The radial expansion of the filament

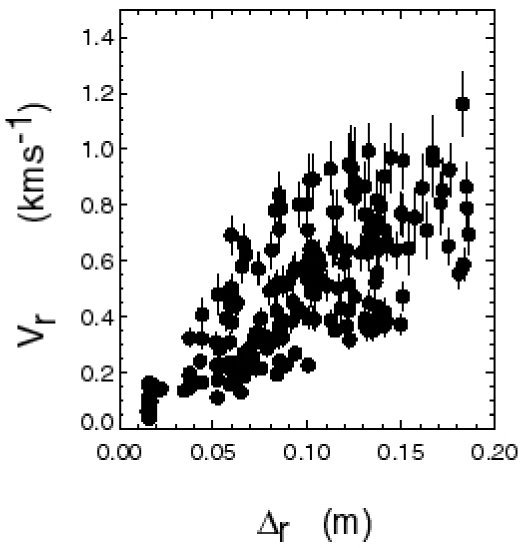
Improvements to the simulation

MAST data

Using distribution of observed V_ϕ and mode numbers and a spread of accelerations in the range 0.5-1.5x10^7 ms^{-2}

Good agreement with the data





Accelerating filaments are expected from the non-linear theory [Wilson and Cowley]

The radial expansion and toroidal structure

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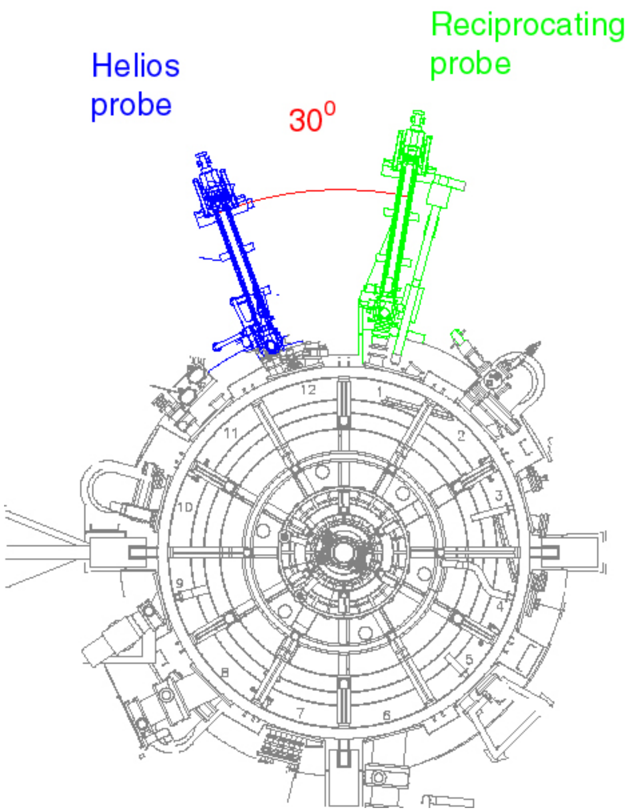

Plan view of MAST

Using two toroidally separated probes located at the same distance from the plasma edge

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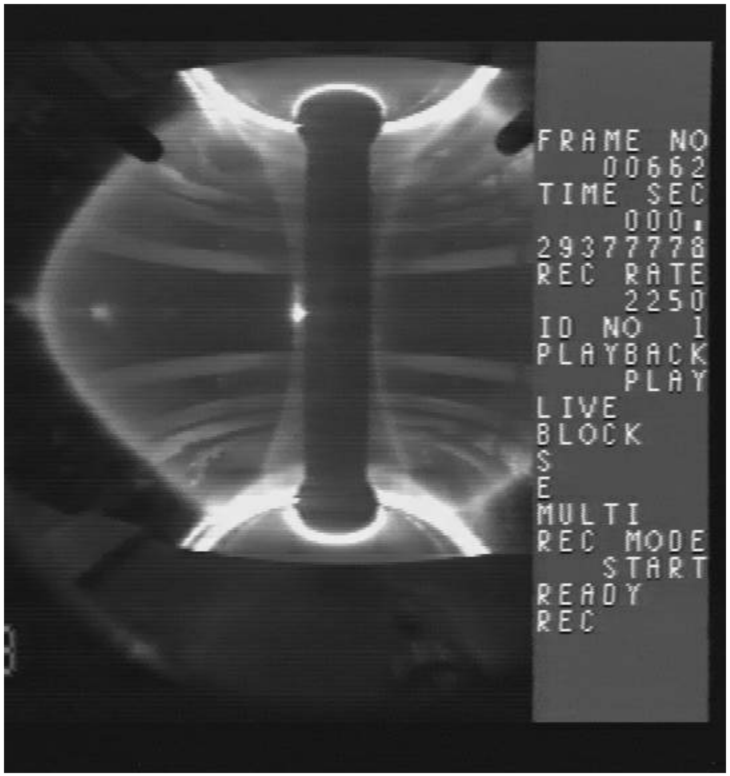
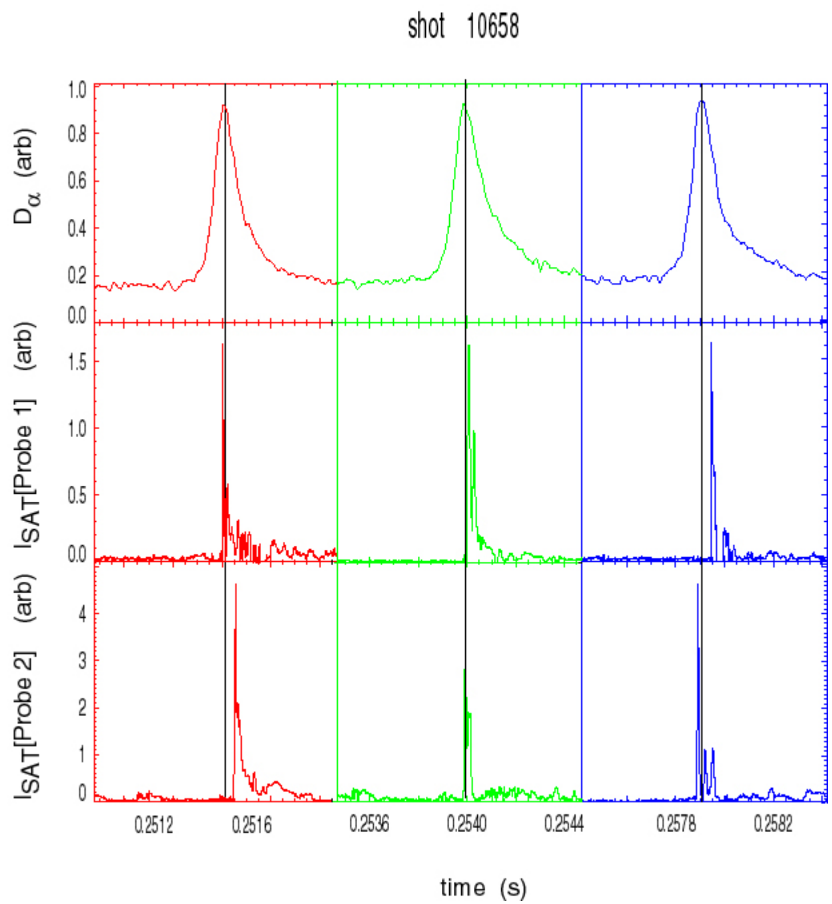
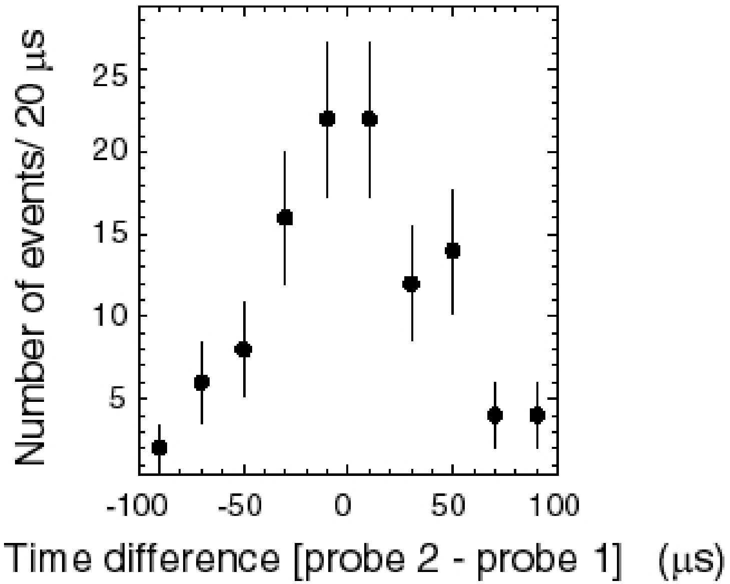
The radial expansion and toroidal structure

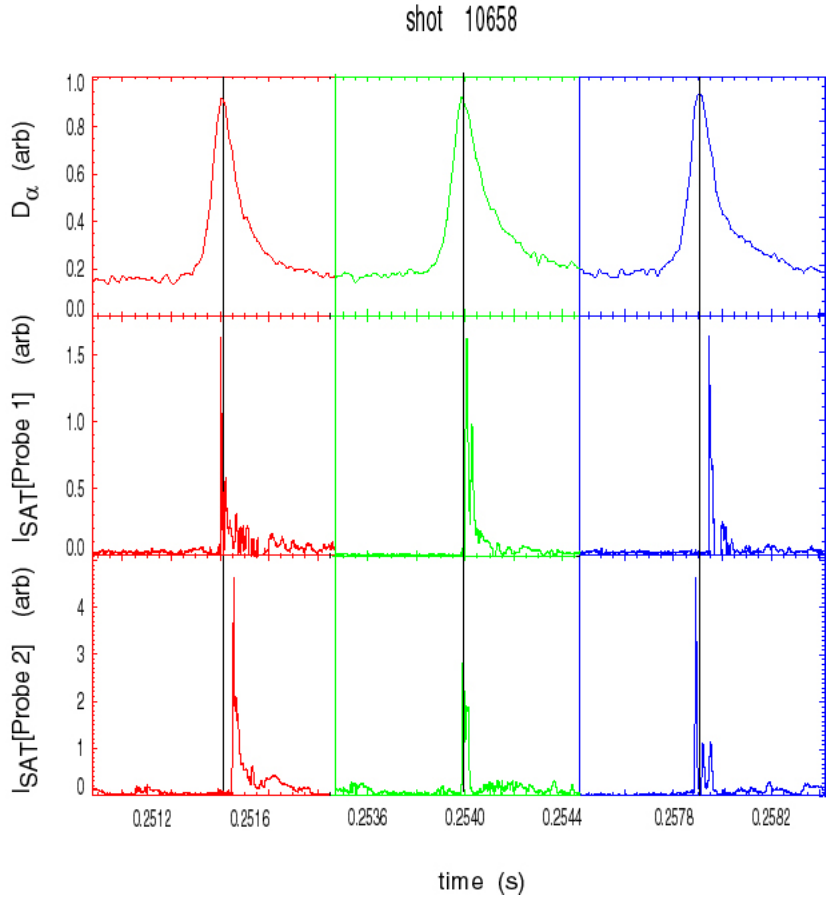




Δt -50 ~ 0 +50 μs

The radial expansion and toroidal structure

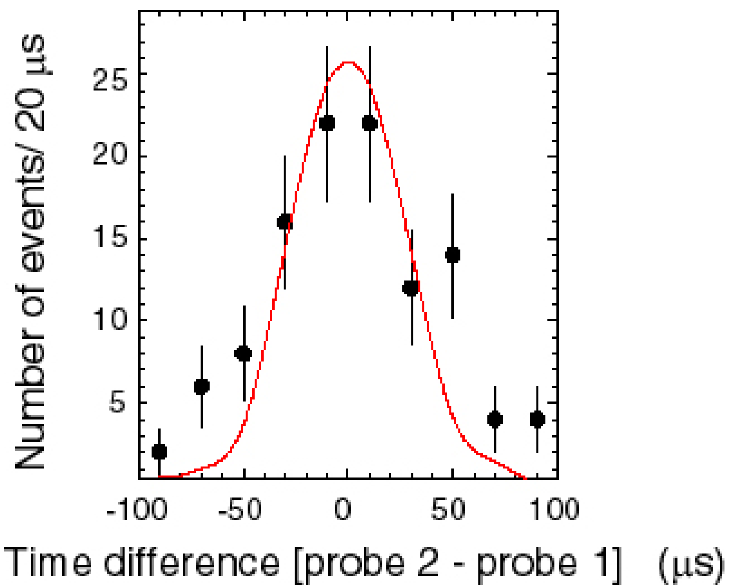




Δt -50 ~ 0 +50 μs

A. Kirk, 20th IAEA Fusion Energy Conference, Vilamoura, Portugal, 2004

The radial expansion and toroidal structure



Results from simulation

using the same

parameters as used for

the radial velocity

Giving further confidence in the n~ 10 filament description of ELMs

Filaments as a pre-cursor to disruptions

The non-linear ballooning mode theory may also play a role in some types of disruptions:

⇒ A low n mode grows near the plasma edge

⇒ exceeding the ballooning mode threshold locally

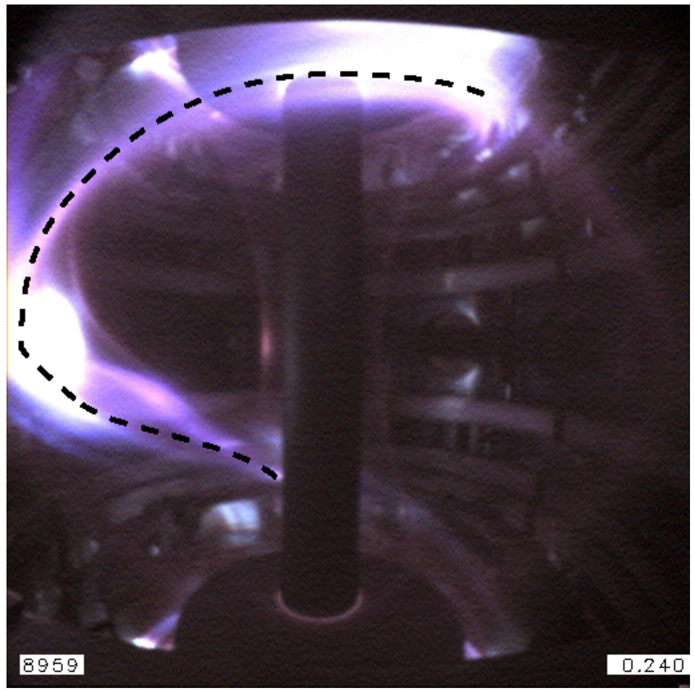
⇒ produces a radially propagating flux tube connected to the core

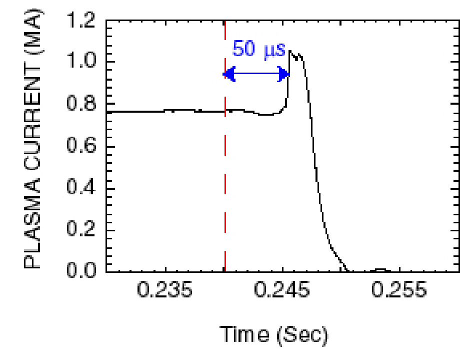
⇒ on contact with plasma facing components - releases impurities that trigger a thermal quench

Filaments as a pre-cursor to disruptions

MAST

Possible evidence for these filaments





Visible images of single (n=1) filaments observed prior to some disruptions

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IR images of the interaction of filaments with vessel components

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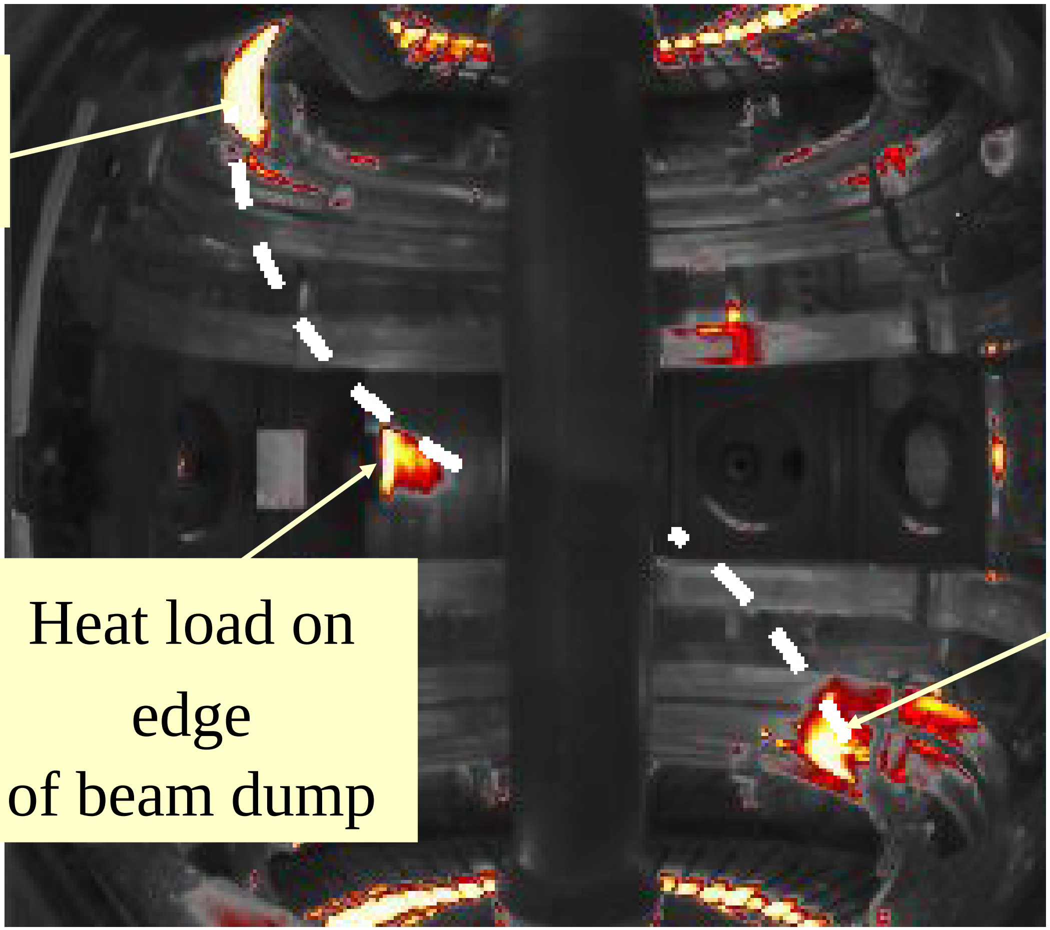
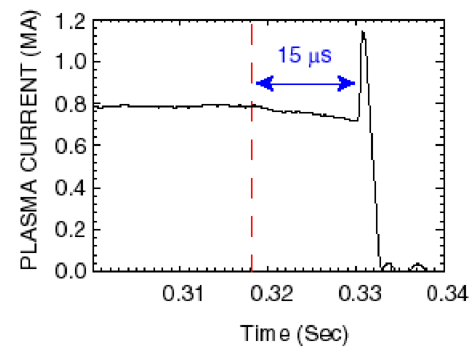
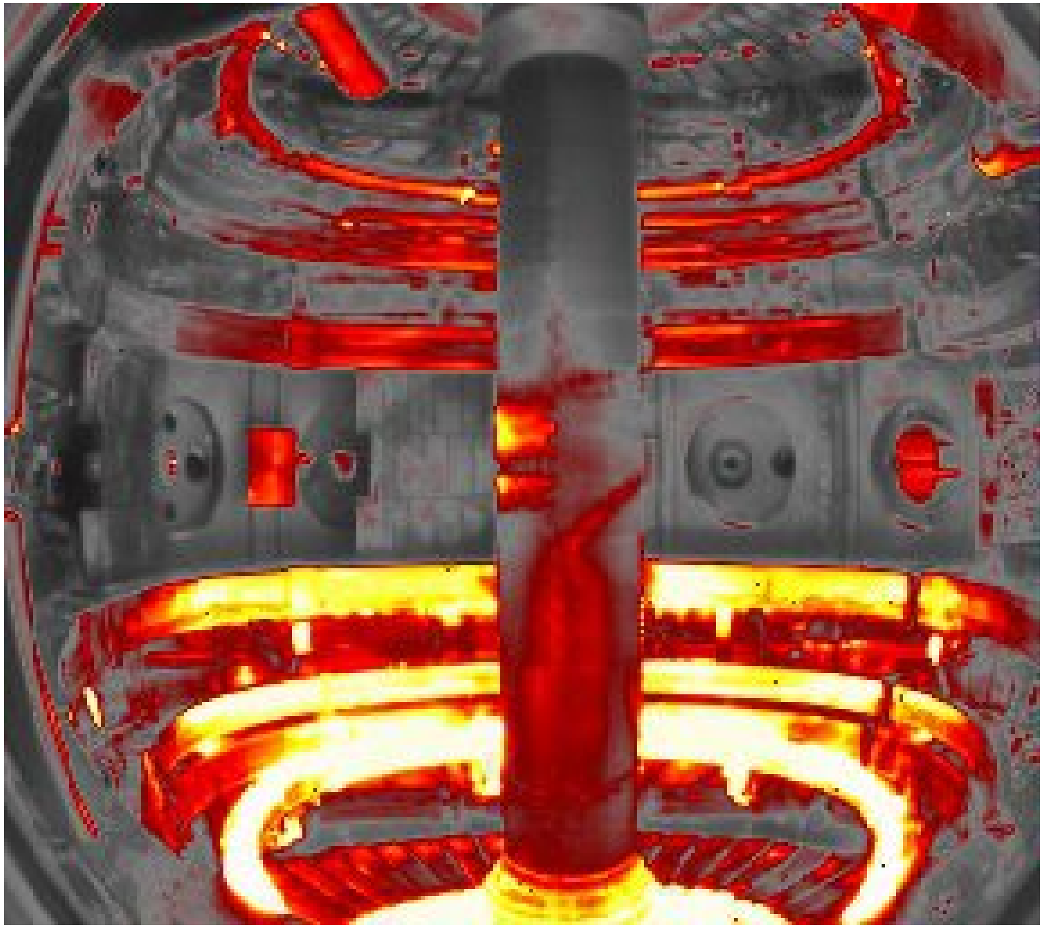




IR images of the interaction of filaments with vessel components



Start of thermal quench

15 ms later

Summary

- There is evidence that filament-like structures exist during ELMs and some types of disruptions, consistent with the predictions of the non-linear evolution of ballooning theory

- In ELMs the filaments are generated on a 100 μs timescale, rotate with the outboard edge of the plasma and accelerate out from the outboard side.

- The importance of these filaments is that they can provide toroidally and poloidally localised heat fluxes to plasma facing components