

# **Fusion Reactor Technology I**

**(459.760, 3 Credits)**

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Plasma Instabilities (Kadomtsev 6, 7, Wood 6)

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Week 11. Heating and Current Drive (Kadomtsev 10)

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Week 13-14. How to Build a Tokamak (Dendy 17 by T. N. Todd)

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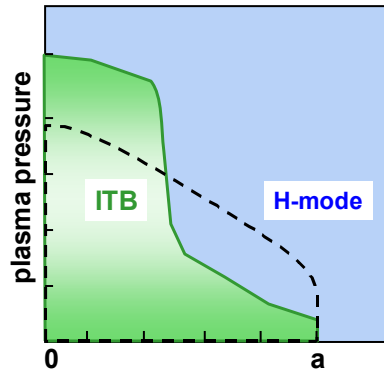
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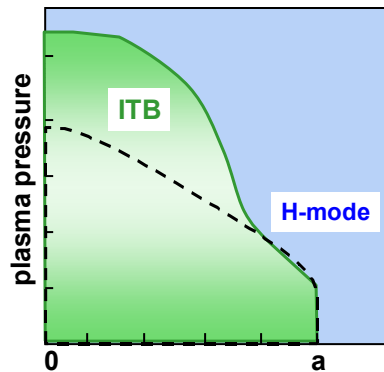
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Week 13-14. How to Build a Tokamak (Dendy 17 by T. N. Todd)

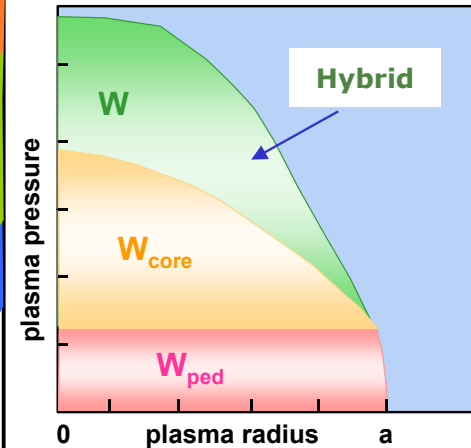
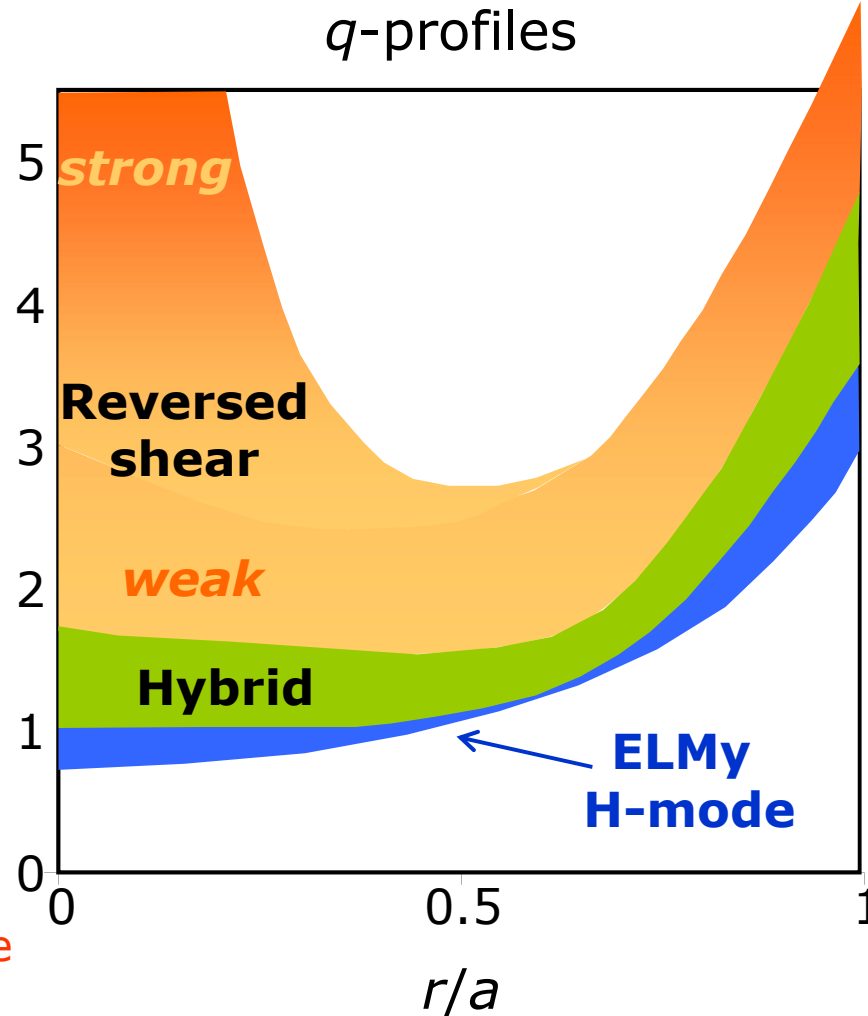
# Tokamak Operation Scenario



- Good confinement
- Poor stability



- Only "weak" RS plasmas are stable but they require a delicate active control



- Good confinement together with high stability w/o active control

# Physics issues for hybrid scenarios

Steadiness of  
the current profile

Confinement  
enhancement

Physics effects  
limiting  $\beta_N$

Impurity  
transport

Role of  $\rho^*$

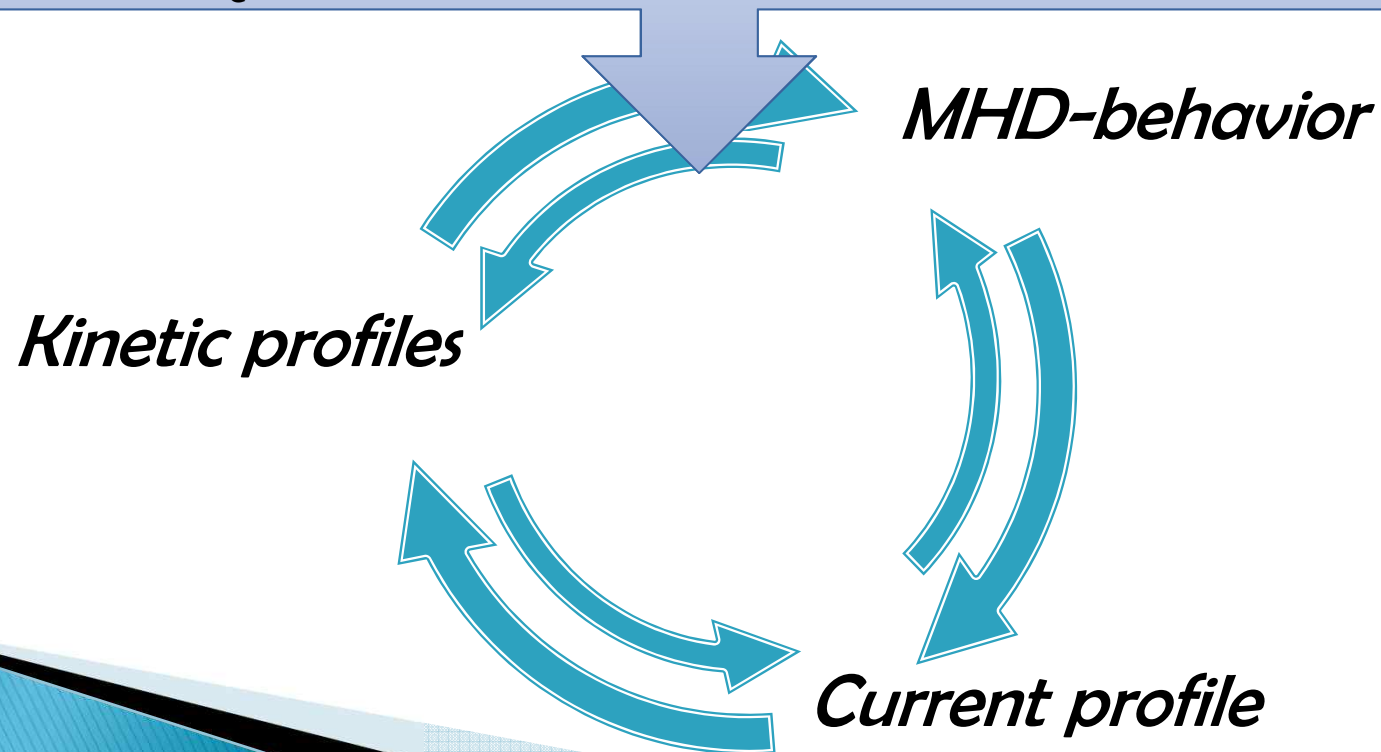
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Normalized Larmor radius which has a significant impact on drift turbulence, on the transport.

# Factors to affect plasma confinement

Several mechanisms seem to play a role :

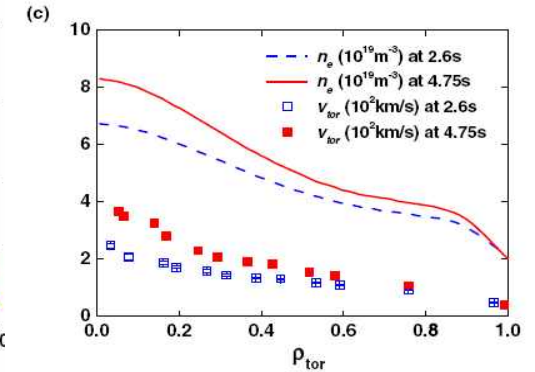
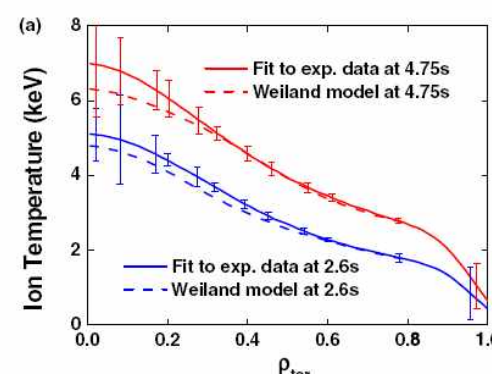
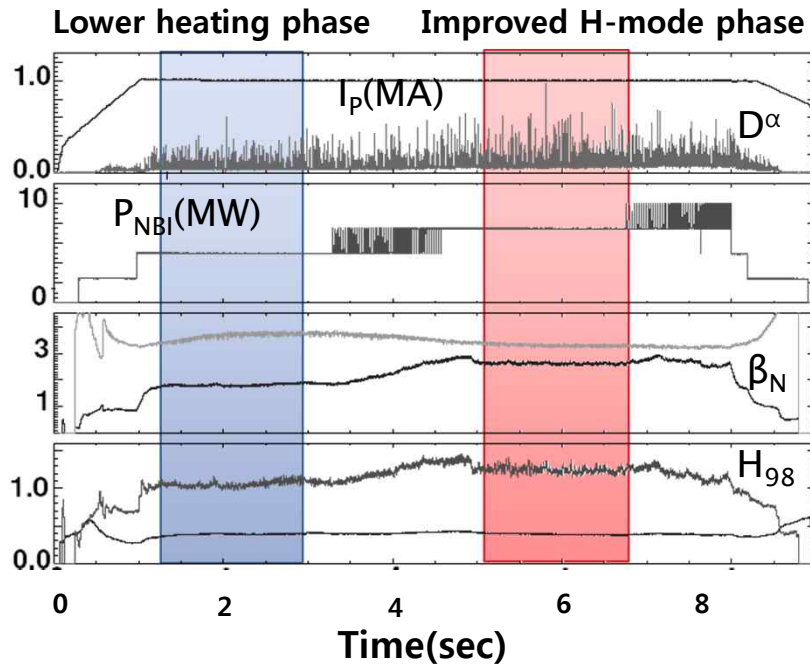
- 1) Effect of H-mode pedestal pressure
- 2) Effect of plasma rotation
- 3) The variation of the ratio magnetic shear( $s$ ) to safety factor( $q$ )
- 4) Effect of fast particle
- 5) Effect of  $\beta_e$



# Attempts to solve physics issues related to confinement

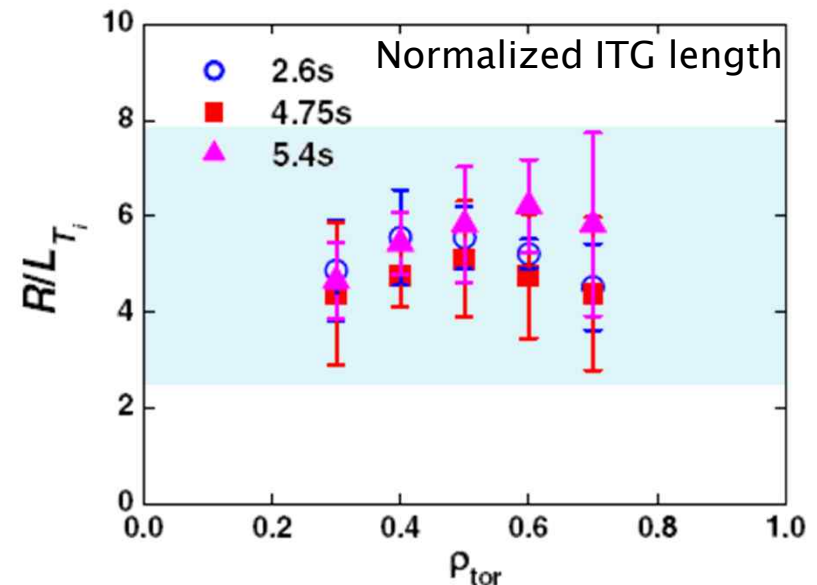
## Role of Pedestal in Hybrid Performance(0)

ASDEX-U, #17870

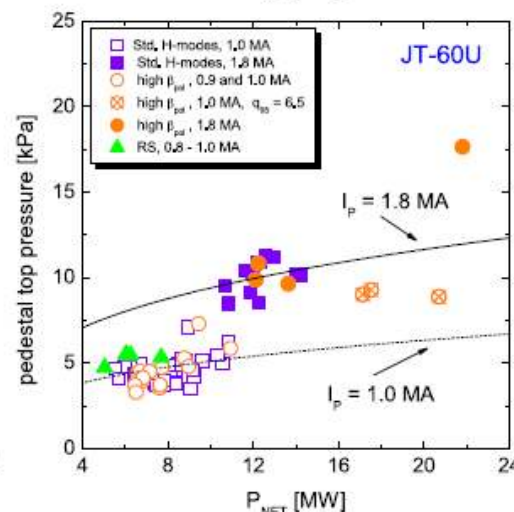
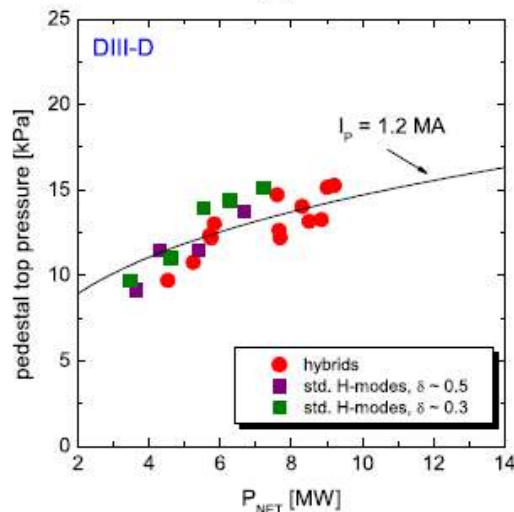
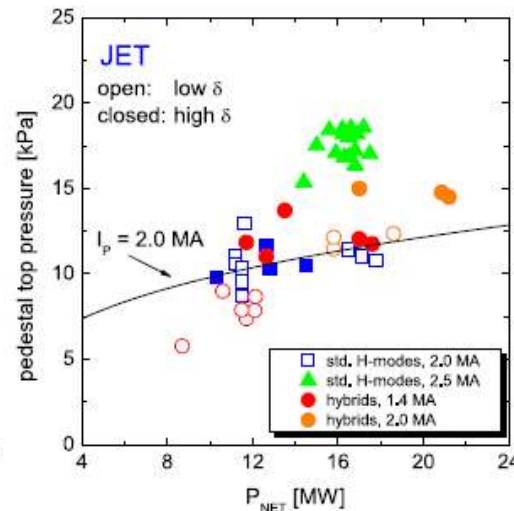
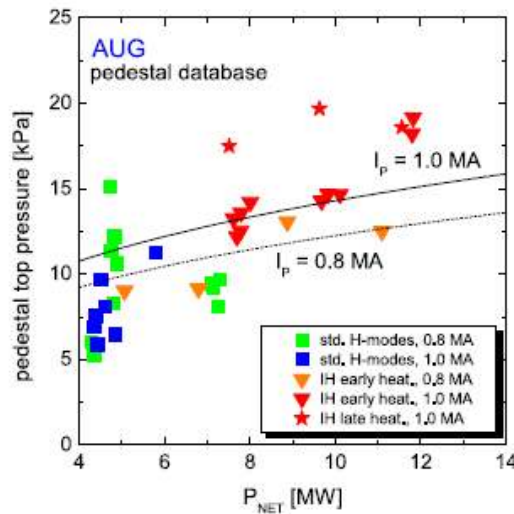


✓ Both phase are still governed by drift-wave turbulence as in standard H-modes.

✓ No difference is found in the behavior of turbulence in the confinement region of the plasma between two phase from the results of the analysis of phase fluctuations.



# Characteristics of the H-mode pedestal in improved confinement scenarios (1)



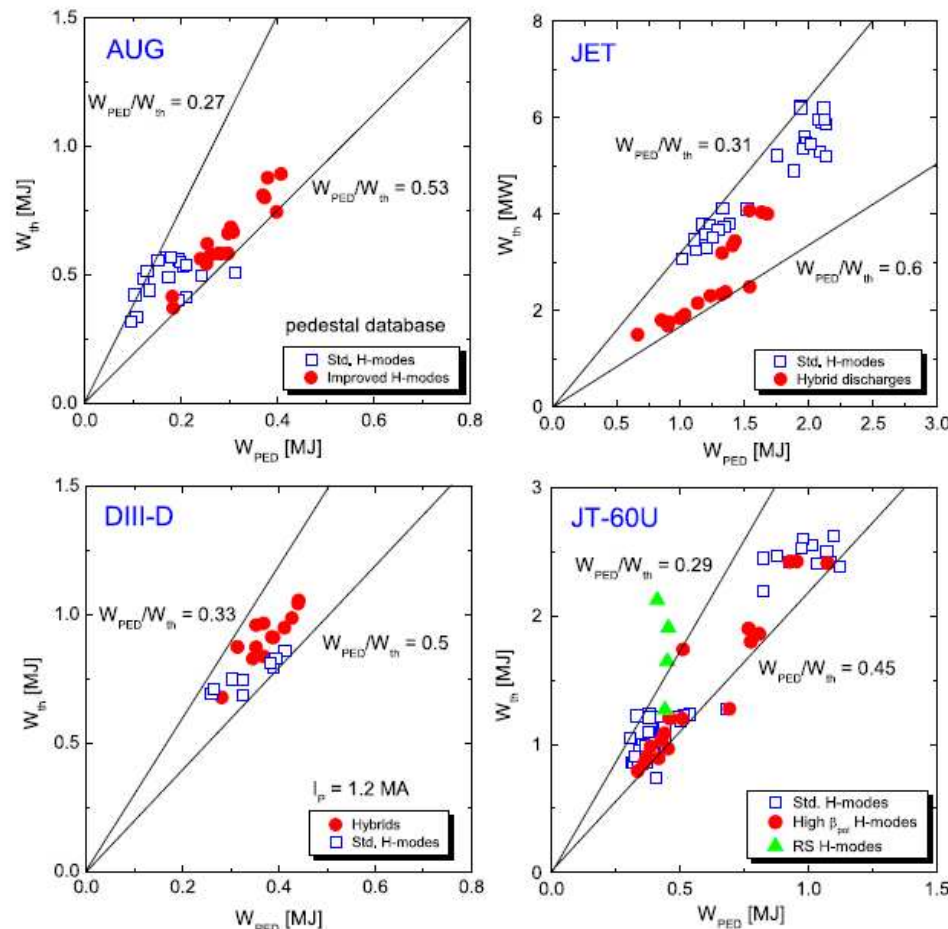
✓ Pedestal top pressure seems to increase moderately with power.

✓ Higher pedestal pressures are observed in improved confinement scenarios

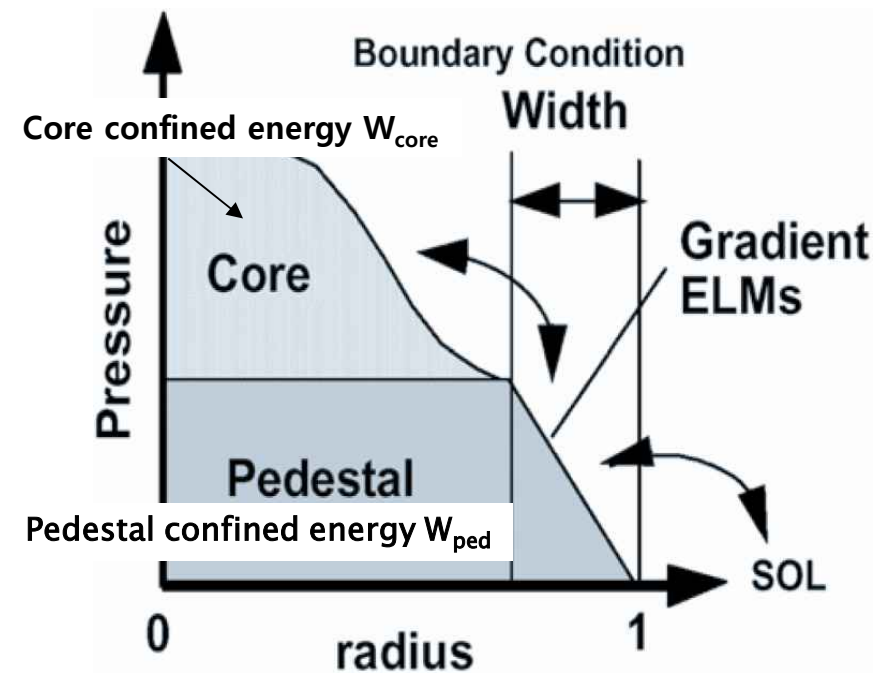


# Characteristics of the H-mode pedestal in improved confinement scenarios (2)

✓ All scenarios has a robust correlation between the total & the pedestal stored energy



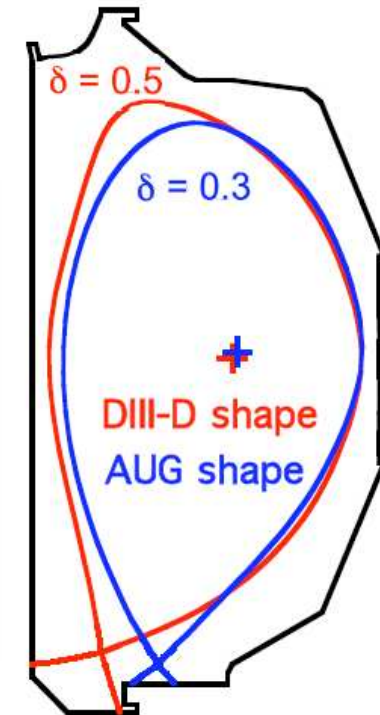
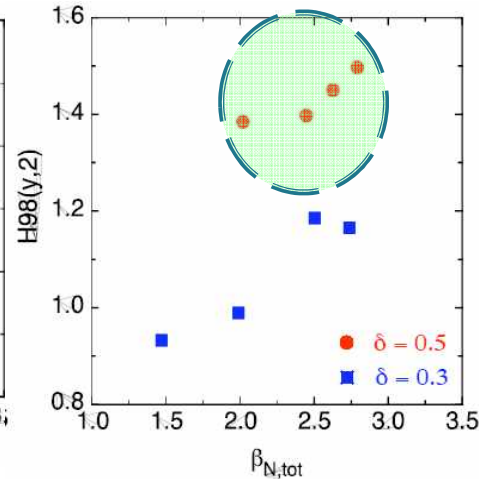
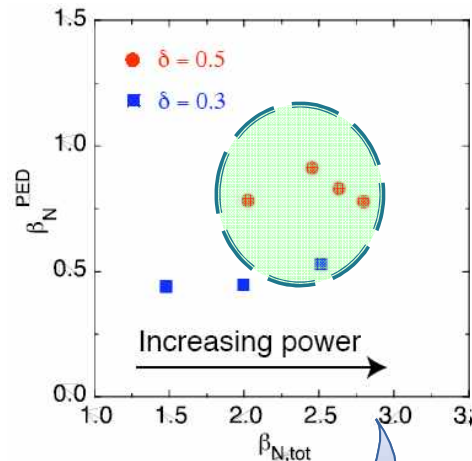
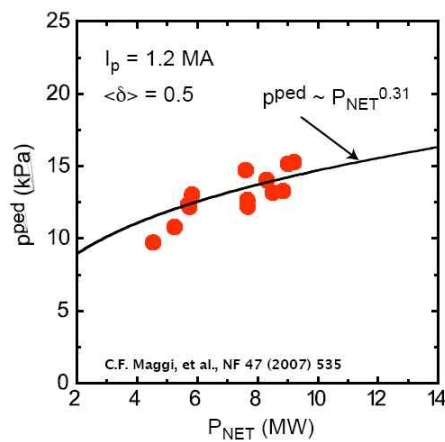
Total stored energy,  $W_{th} = W_{ped} + W_{core}$



# Attempts to solve physics issues related to confinement

## Role of Pedestal in Hybrid Performance(1)

- ✓ Initial survey showed that  
“There is a trend for pedestal pressure to increase with heating power.”
- ✓ Also, plasma shape can be used to improve hybrid performance through pedestal effects.

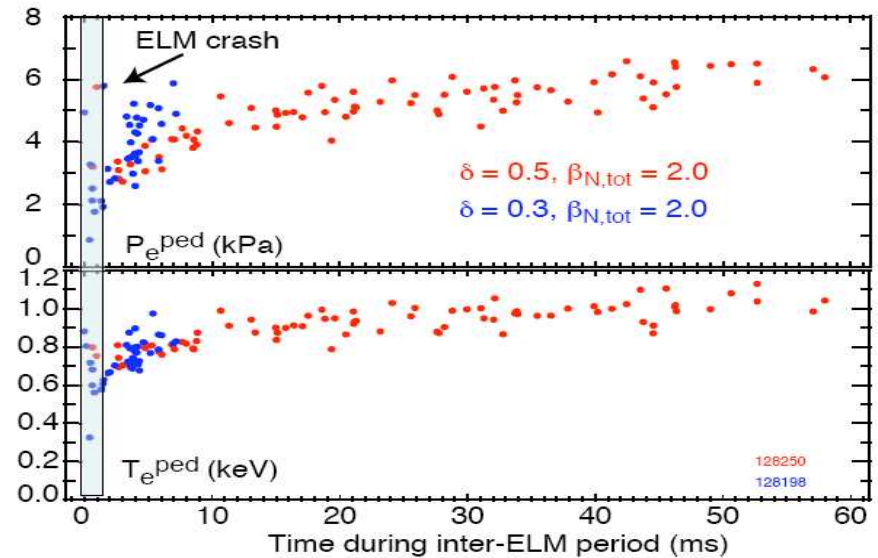
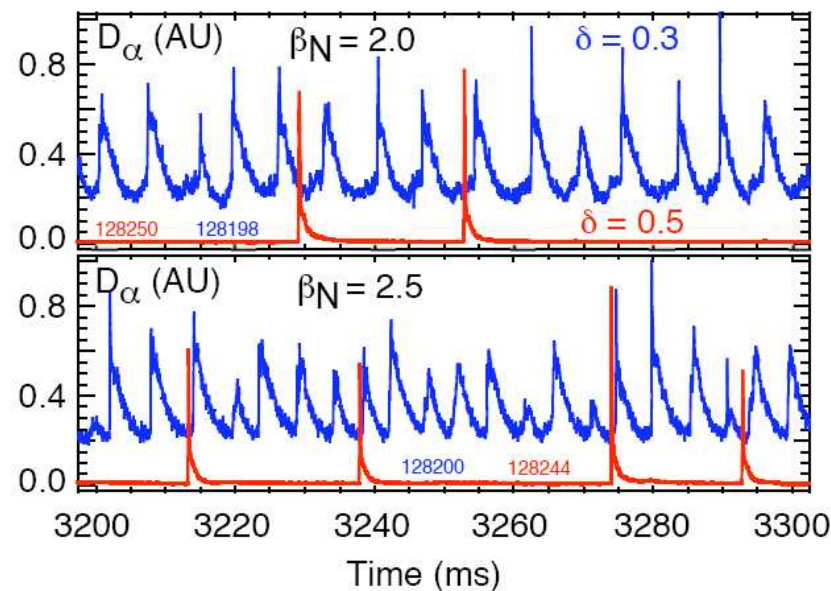


- ✓ Hybrids exhibit some confinement enhancements which cannot be attributed to pedestal  
: Core stored energy can increase even when pedestal pressure does not increase with increased power

# Attempts to solve physics issues related to confinement

## Role of Pedestal in Hybrid Performance(2)

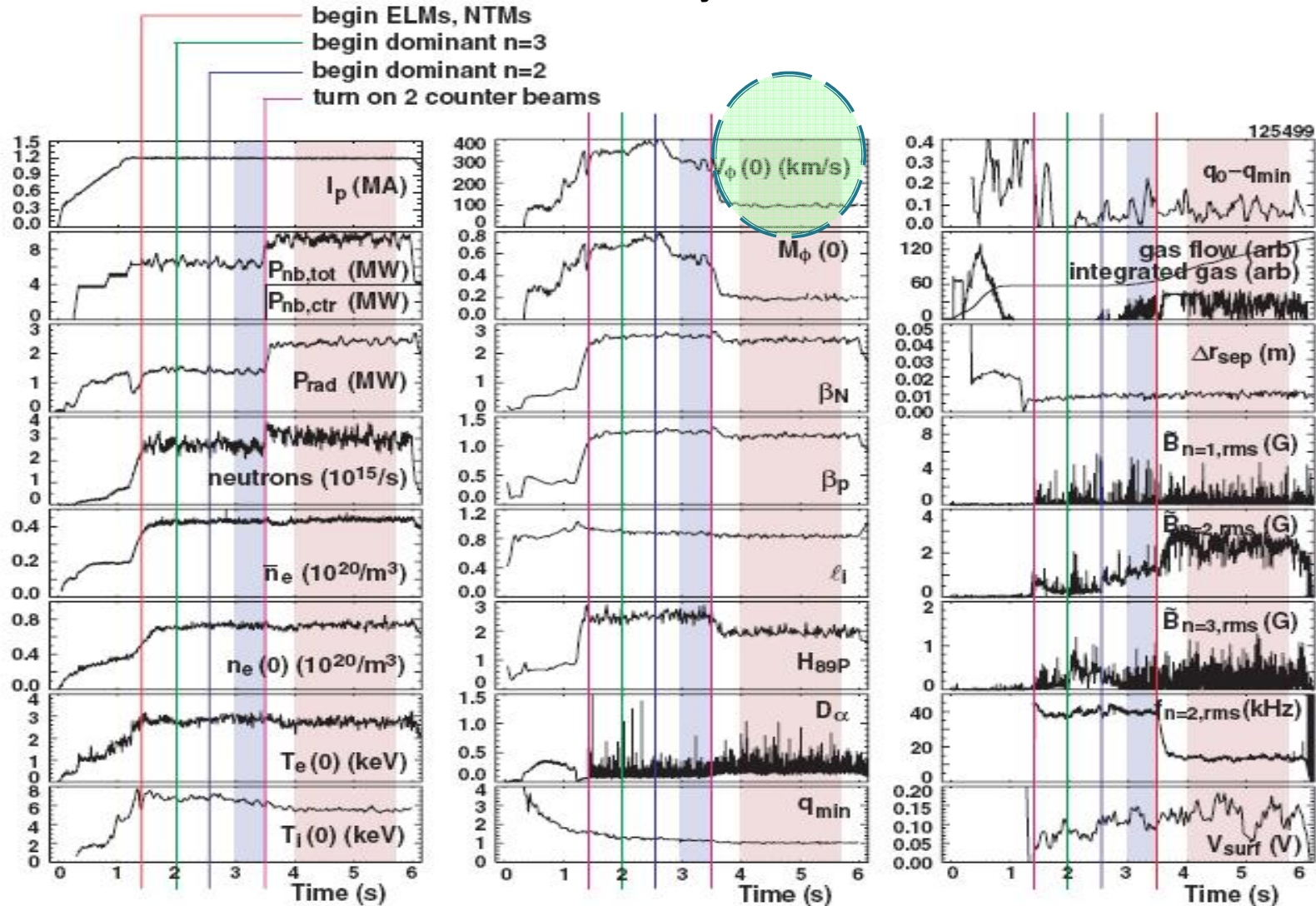
- ✓ Higher pedestals are correlated with lower ELM frequencies.
  - Lower ELM frequency may allow more complete recovery of pedestal after an ELM and thus higher time-averaged pedestal pressure.
  - Physics relation between high and low ELM frequency not clear.



# Attempts to solve physics issues related to confinement

## Influence of toroidal rotation(1)

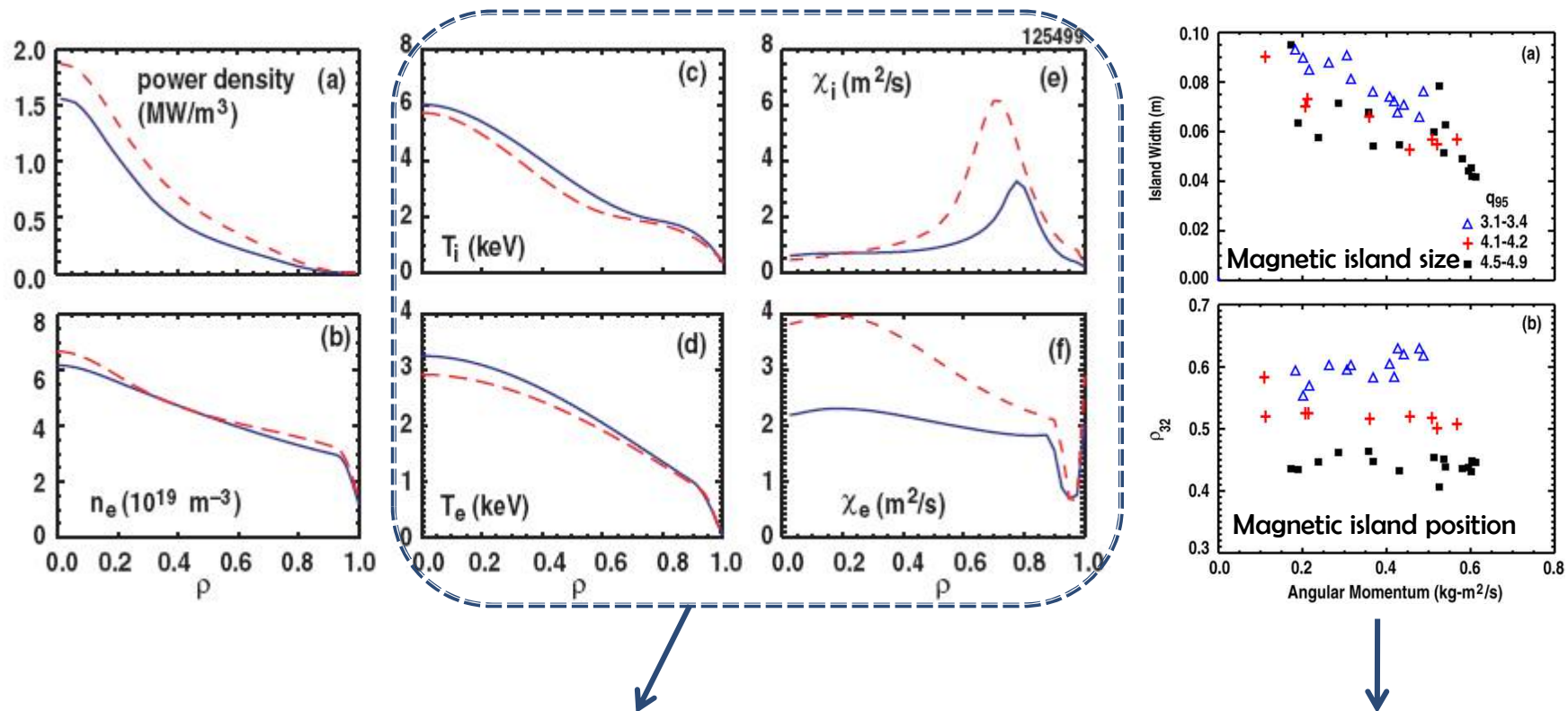
✓ Experiment in DIII-D with co- & counter NBI system



# Attempts to solve physics issues related to confinement

## Influence of toroidal rotation(2)

- ✓ Comparison between strong (blue) and low (red) toroidal rotation intervals.

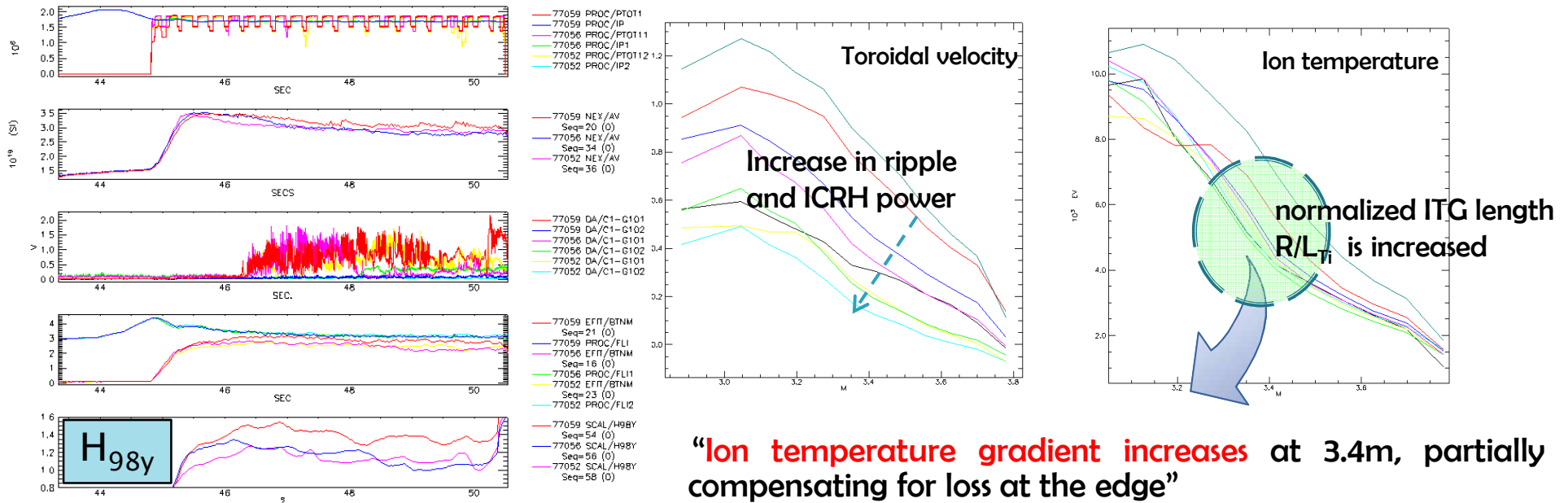


- Although energy confinement decreases and the  $m/n=3/2$  NTM amplitude increases for low rotation speed, the fusion performance figure of merit still exceeds the value required on ITER for  $Q=10$ .

# Attempts to solve physics issues related to confinement

## Influence of toroidal rotation(3)

✓ Strong change in rotation achieved, by ripple and EFCCs in JET

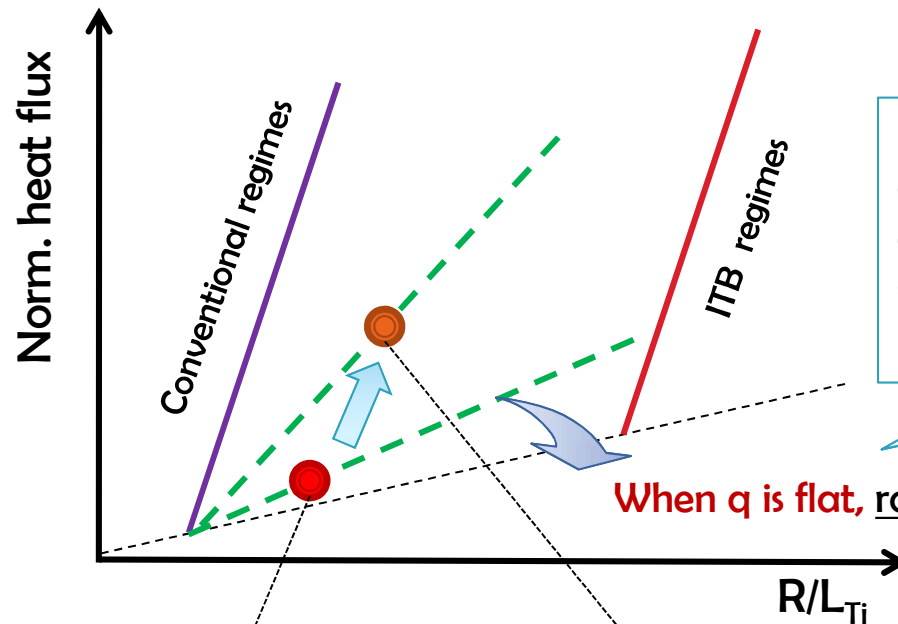


- Clear confinement reduction with ripple and EFCCs
- Density reduced as well, ELMs are different
- q-profile seems to be similar

# Attempts to solve physics issues related to confinement

## Influence of toroidal rotation(4)

- ✓ the effect of rotation on ion transport



by P. Mantica

“It does not exclude a shift in threshold due to other parameters. It does not exclude Waltz rule but it is a much smaller effect. In fact not enough as we have seen many times.”

When  $q$  is flat, rotation reduces stiffness

No ripple, higher rotation, low stiffness, higher pedestal(lower heat flux)

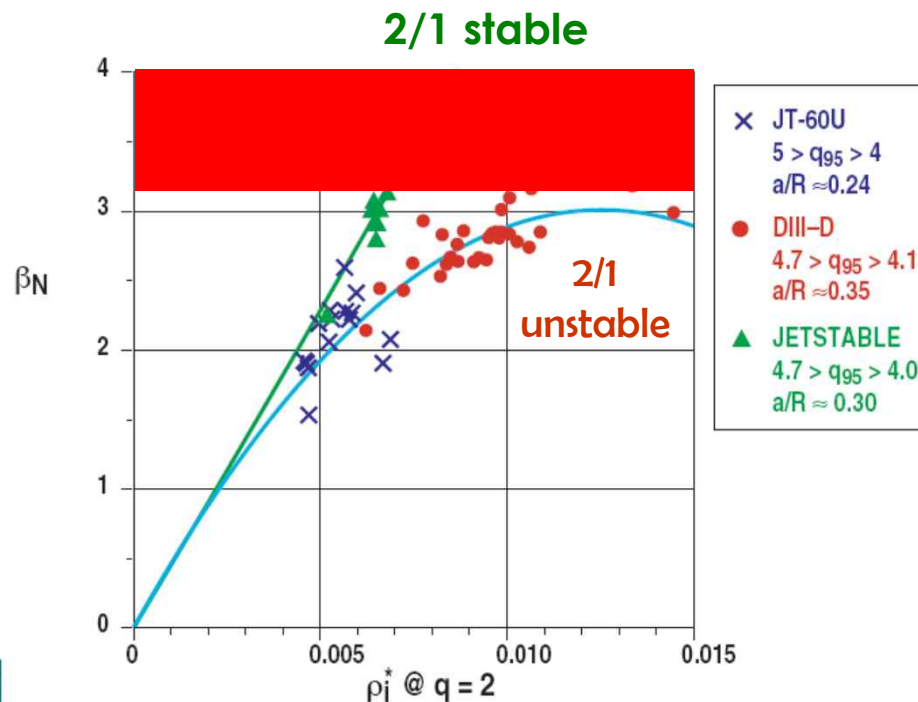
Ripple, bit lower rotation, bit higher stiffness, lower pedestal(higher heat flux)

# Attempts to solve physics issues related to confinement

## Fast particle effects on the stability limits

JET stable to 2/1 not DIII-D

- Different **fast particle content?**
- Different **q profile?**



cf.1. Preliminary computation on JET pulses with the HAGIS code indicate that the internal kink mode limit shows a different instability limit when a fraction of fast ion pressure is included in the total pressure.

$\beta_N$  limit can change by ~20%

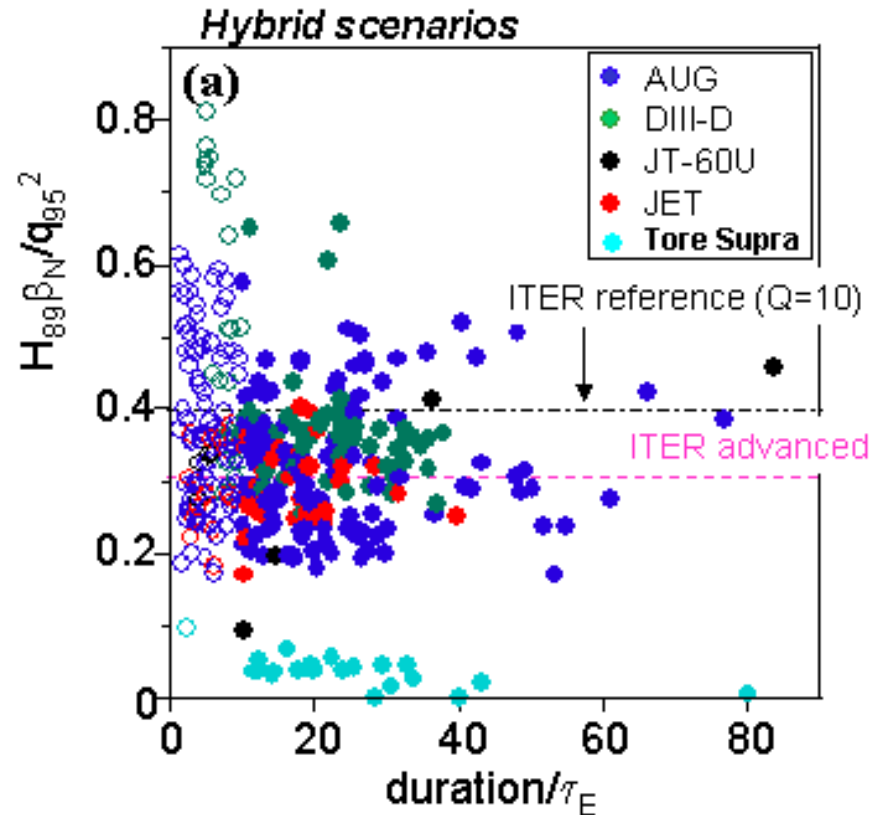
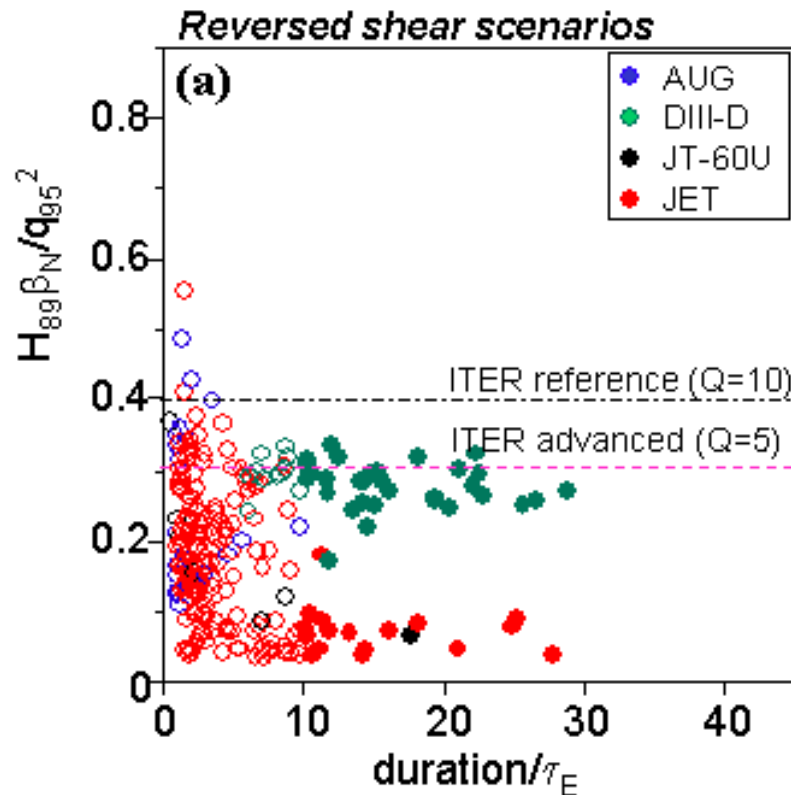
cf.2. Fast particles have a stabilizing effect on ITG driven modes through a modification of the magnetic equilibrium (incidentally improve the gyro-kinetic ordering)



# Progress for Hybrid Scenario

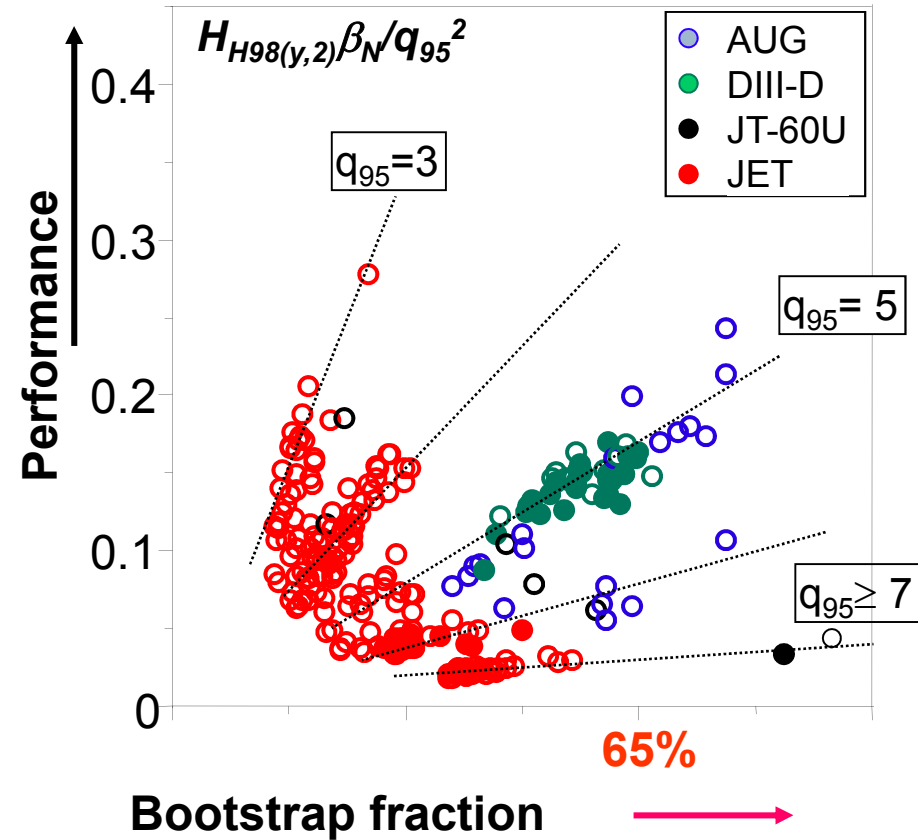
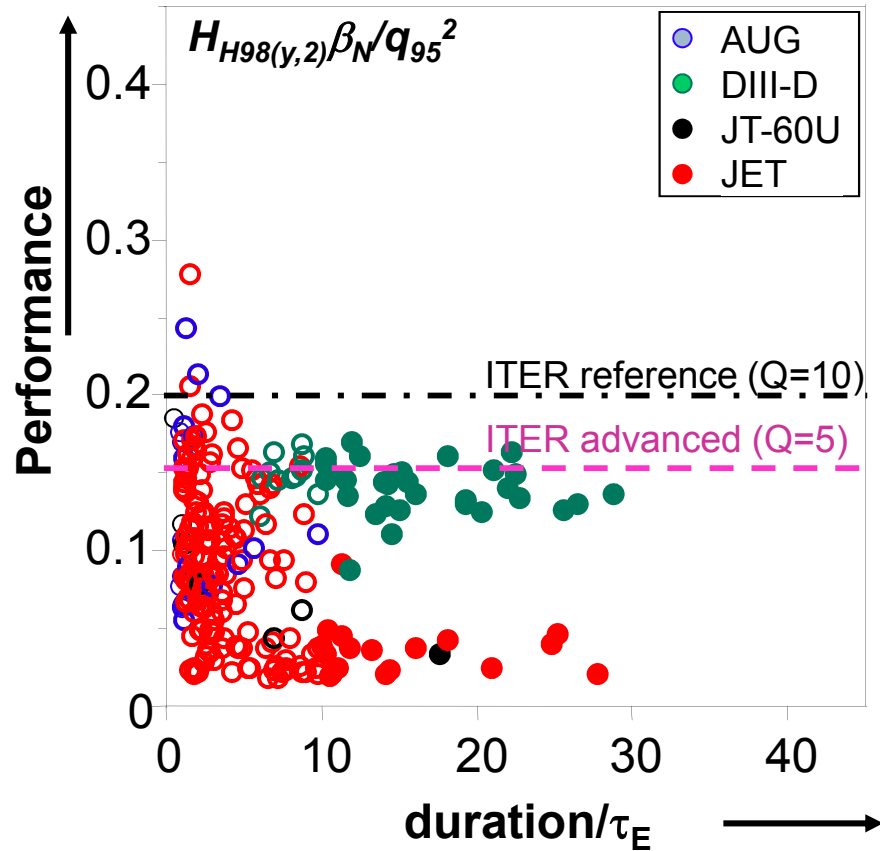
## ITPA database for plasma performance as duration time

(open symbols are transient discharges, closed symbols are stationary ones)



- ✓ The duration of hybrid discharges is typically longer compared to reversed shear plasmas.
- ✓ There is no clear difference between the various experiments in hybrid dataset.

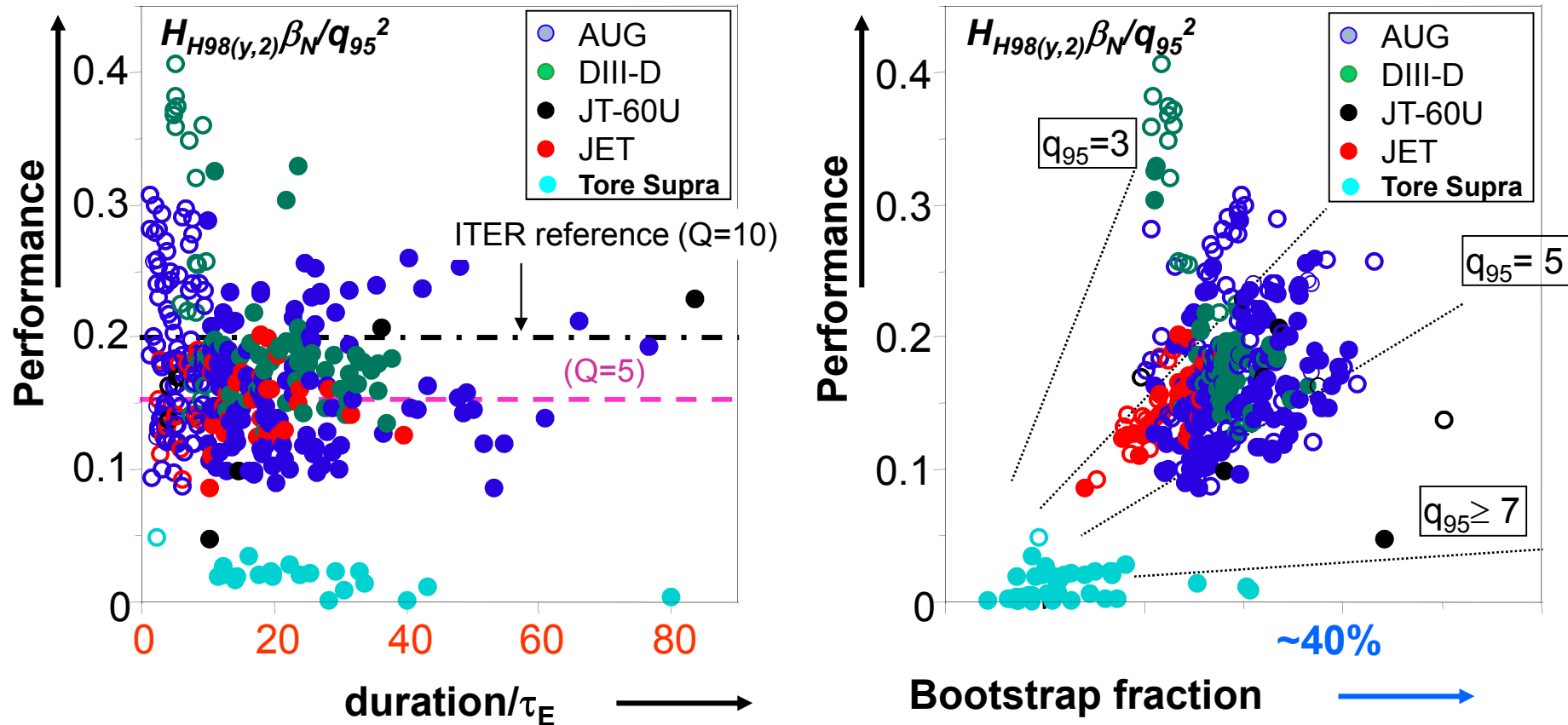
# Reversed Shear Scenario



Distinct groups of results, best ones just fine for Q~5.

Transient for  $q_{95}\leq 4$ , ITER target for  $q_{95}=5$  only.

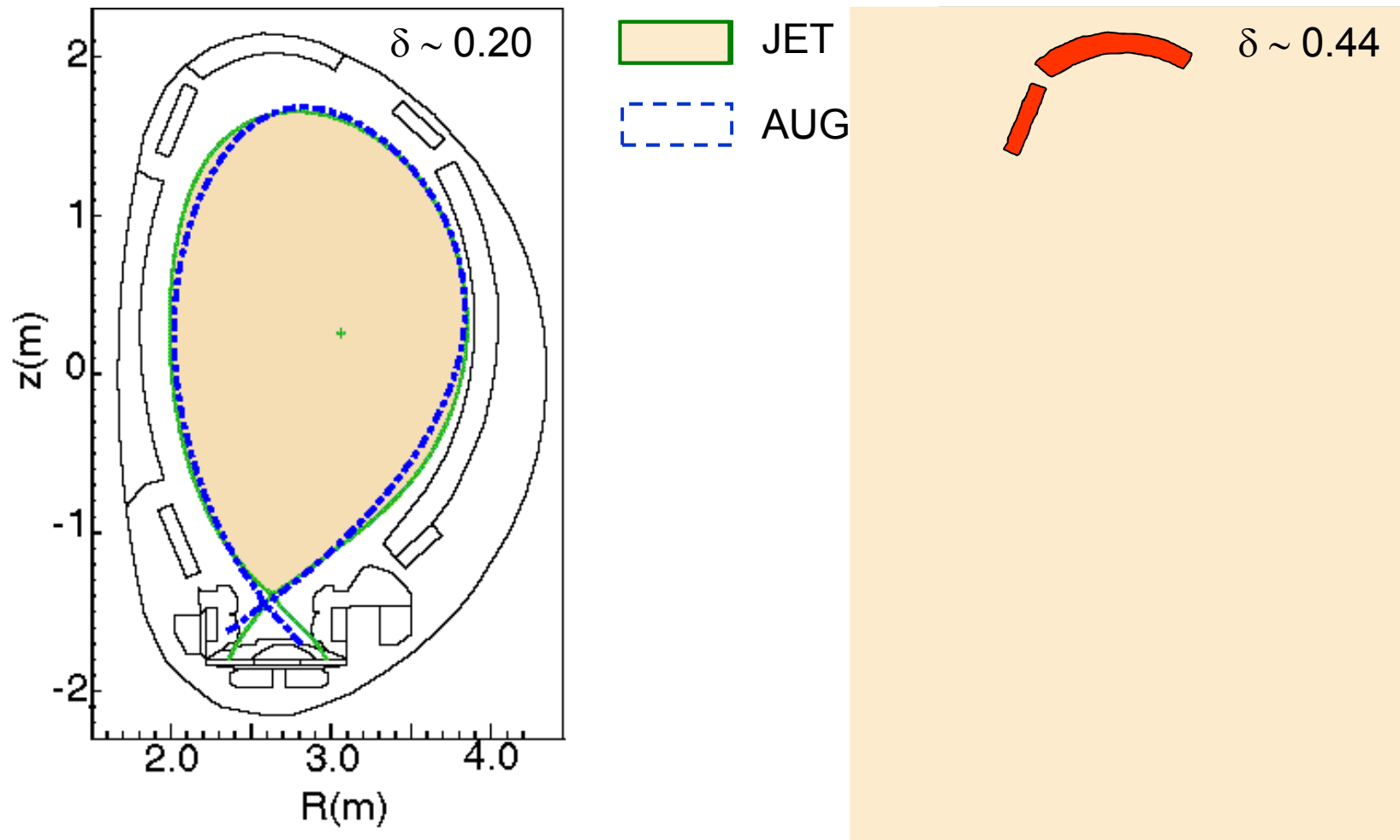
# Hybrid Scenario



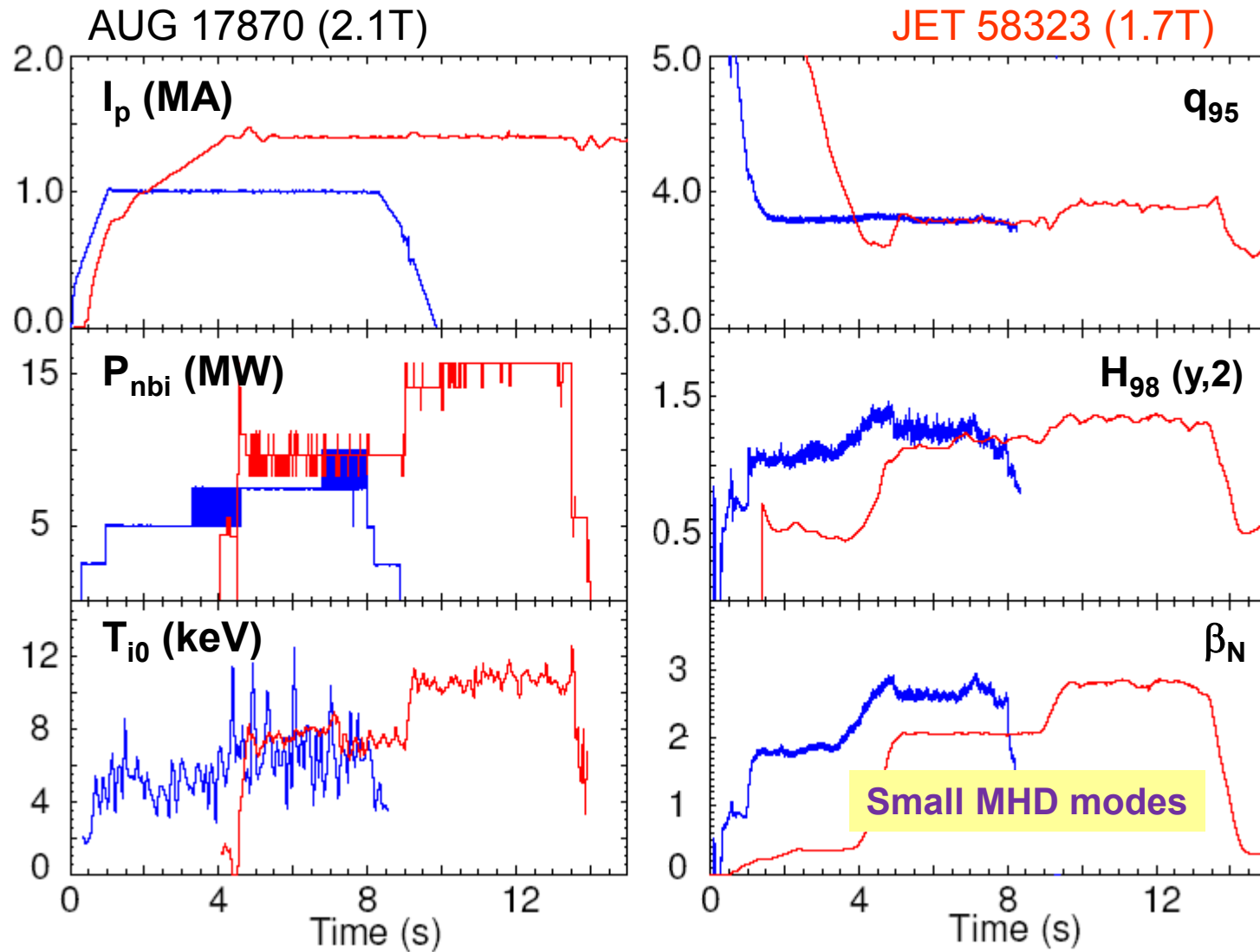
Similar results from all machines,  $Q > 10$  possible (ignition?).  
2x ITER target at  $q_{95}=3$ , or long pulse (2000s) at  $q_{95}=4-4.5$ .

# Identity Experiments

## Plasma shapes used in JET compared to ASDEX Upgrade

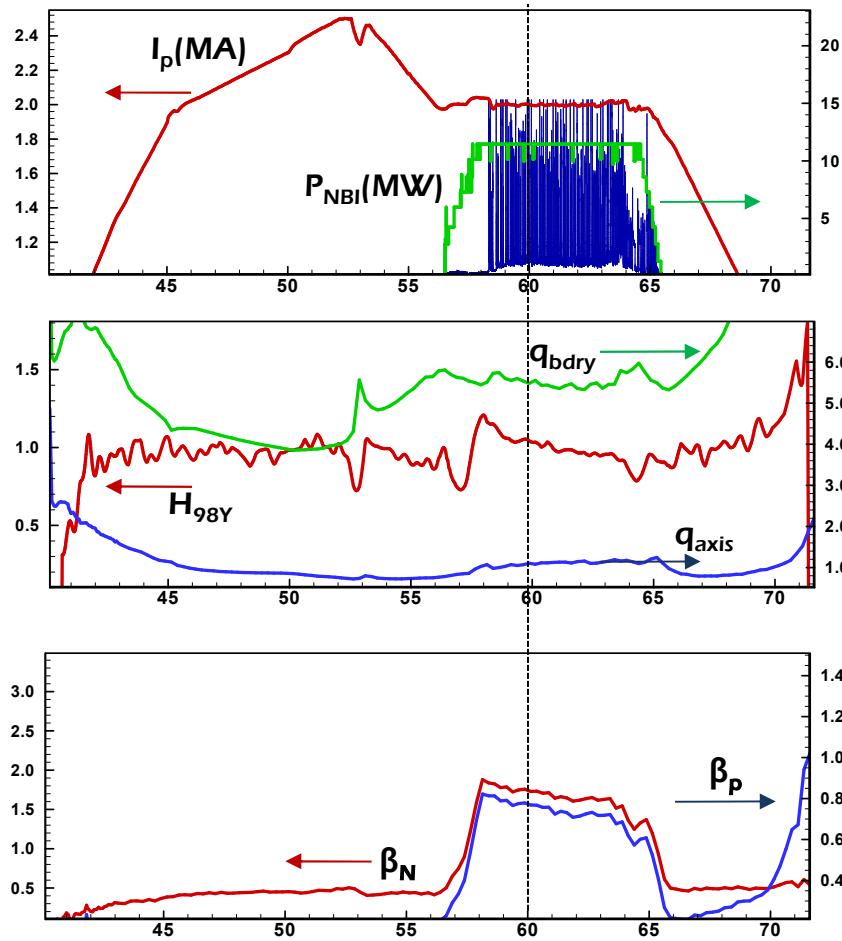


# Identity Experiments

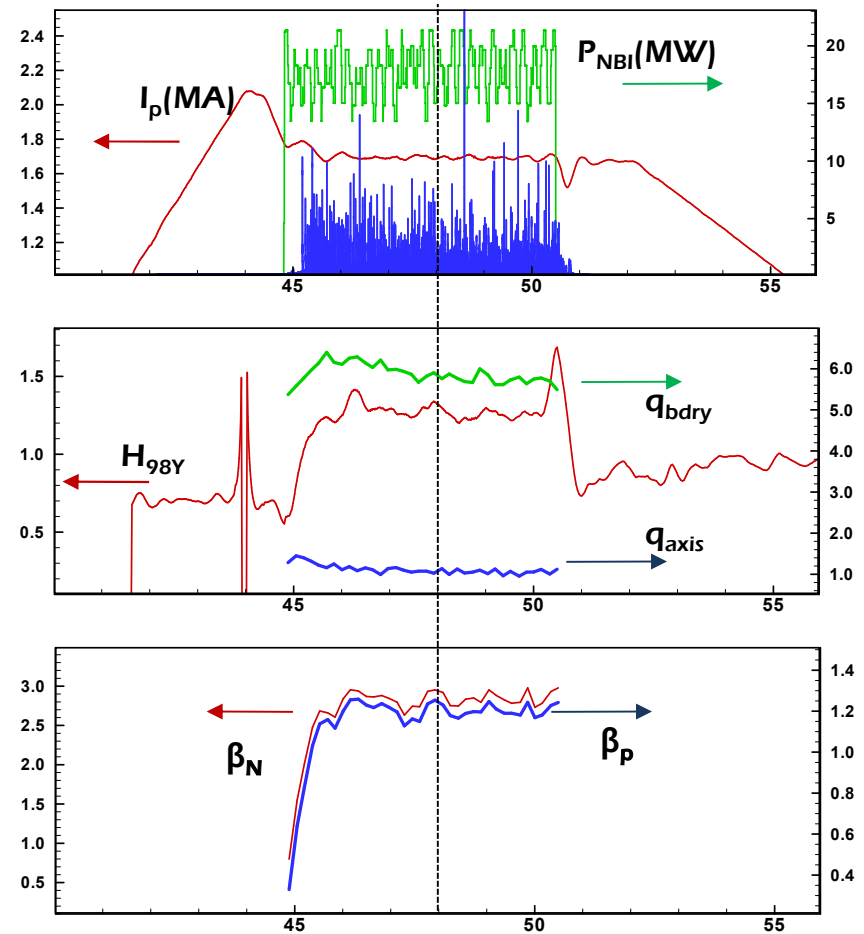


# MHD Analysis on JET Shots

#55937 (an example of conventional H-mode)



#75738 (an example of Hybrid scenario)



----- analyzed time (before ELM burst)