# *Compatibility of high performance scenarios with ILW*

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# Background

## JET-C up to 2009

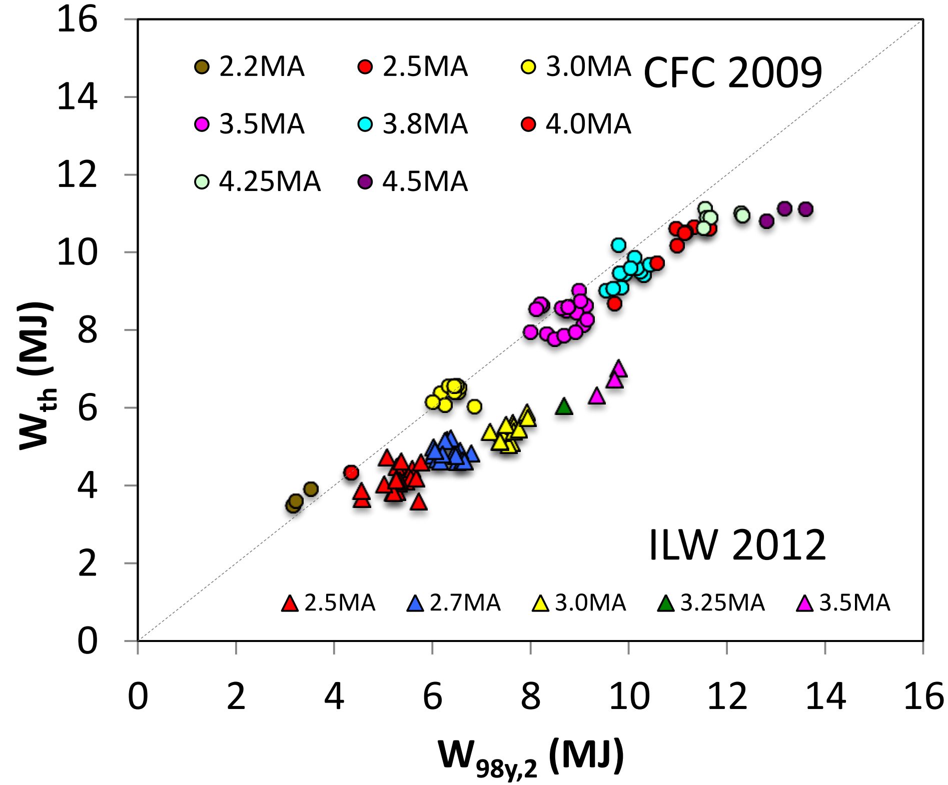
- Mainly unfuelled plasma up to 3.8MA with good confinement
- Above 3.8MA → high gas dosing to mitigate 1MJ ELMs

## JET-ILW 2012

- Development reached 3.5MA, although reduced confinement

## Aim JET-ILW 2014

- Recover confinement
- Achieve 4MA

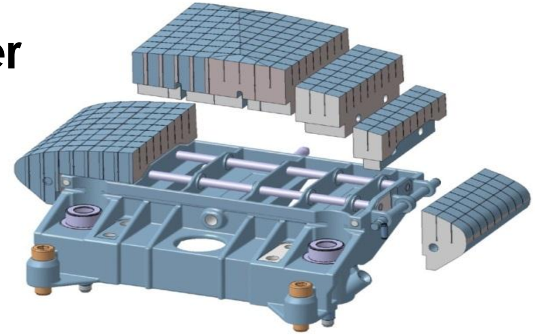


# Outline

- **Scenario choices/strategies**
- **Integration into the scenario** of:
  - Control of W core accumulation
  - Divertor heat load control
- **Confinement**
- **Summary and future prospects**

# Operational limits on JET PFCs

**Be limiter**

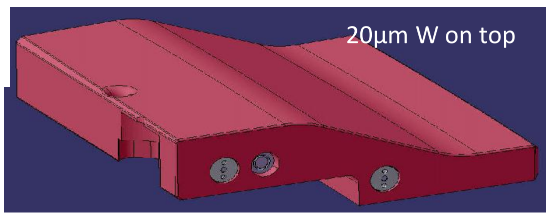


*Solid Be limiter*

- Surface temperature limit: **900°C**
- Heat flux factor: 22 $MJm^{-2}s^{-1/2}$

V. Riccardo et al. Phys. Scripta 2010
Ph. Mertens et al. J. Nucl. Mater 2013

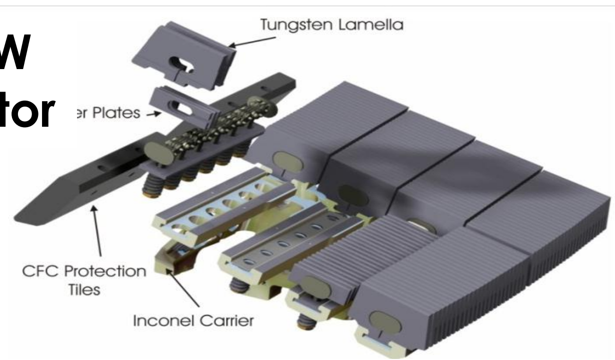
**W-coated CFC**




*W-coated CFC divertor tiles*

- Surface temperature limit: **1200°C**
- Energy limit: 250 MJ / row

**Bulk W divertor**



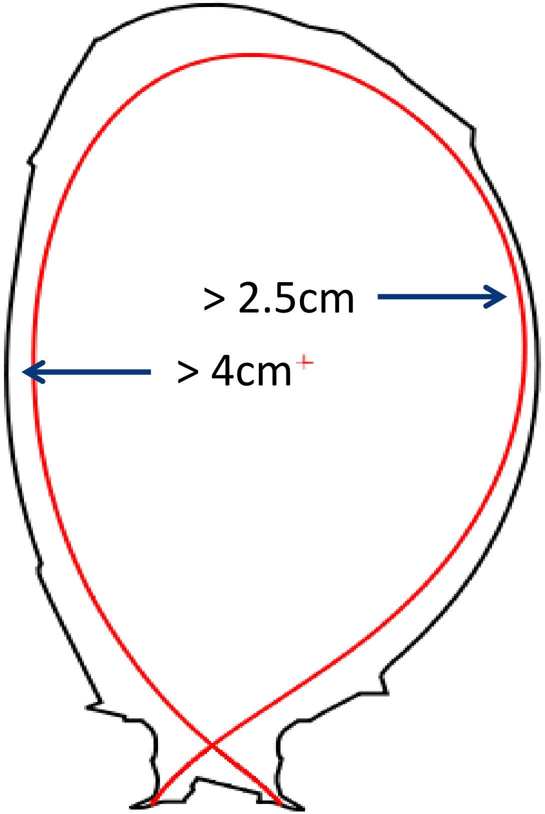

*Bulk W divertor*

- Surface temperature limit: **1000°C**
- Heat flux factor: 35 $MJm^{-2}s^{-1/2}$
- Energy limit: 60 $MJm^{-2}$ or stack

4MA H-mode → ~500-700 tones + ~20MJ of energy
Margin of a factor of 2 against serious damage to the vessel

**Scenario optimised for**

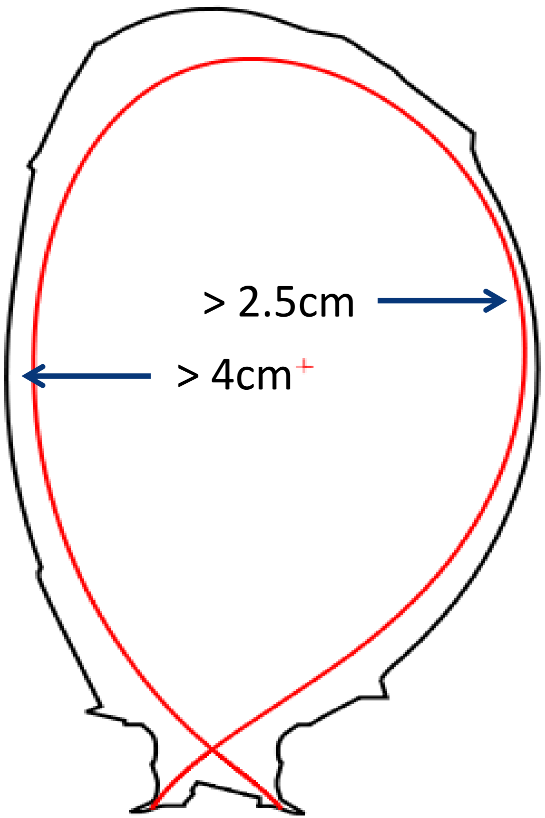
- Minimum disruption force – minimise PF currents
- Maximum $I_p$ within currents coils constraints → low triangularity
- Maximise $q_{95}$ for given $I_p/B_T$ → large volume
- Avoid plasma-wall contact



# Scenario choices and strategies

**Special care**

- $I_P$ ramp-up → low li to optimise volume
- $I_P$ ramp-down (high li) balance between
  - fast $I_p$ ramp-down → reduce disruption force
  - Shrink plasma to avoid wall contact → increase PF → increase disruption forces
- Disruption avoidance
  - Early detection of off-normal events
- **MGI if disruption unavoidable**



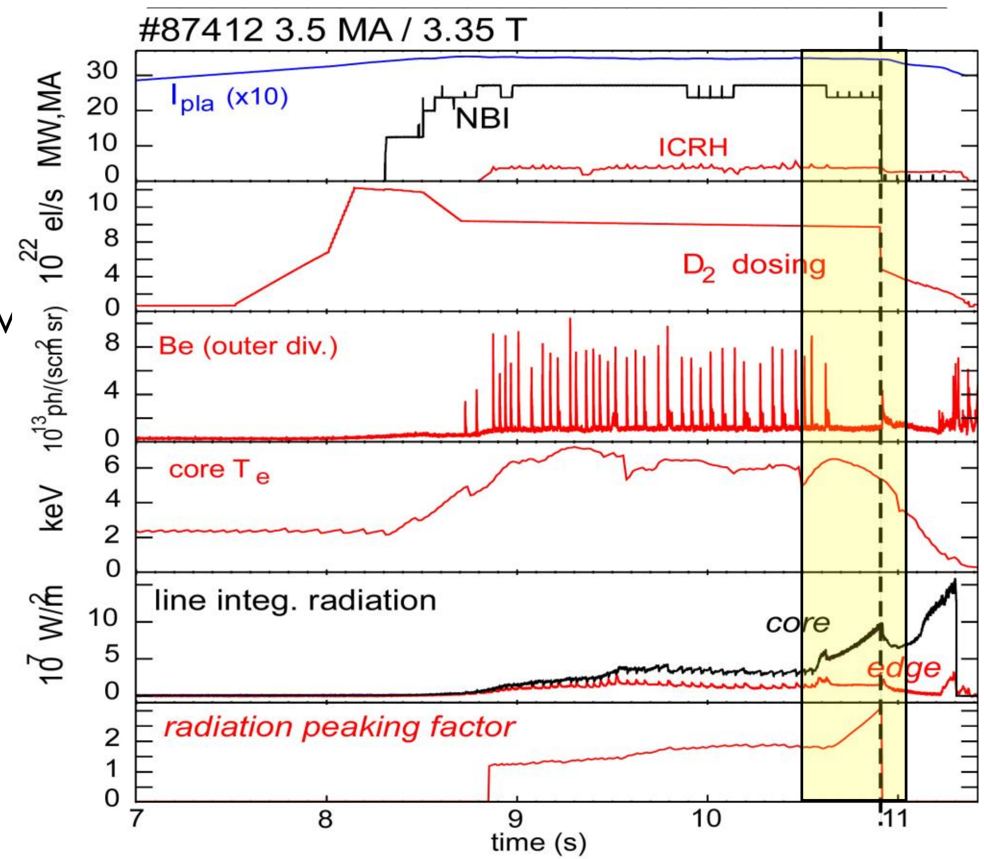
# High-Z impurity accumulation

Most common cause of off-normal event ➔ High-Z impurity accumulation
(50% likely to disrupt)

- NBI switch-off
- ELM frequency decreases
- W concentration in core increases
- temperature profiles become hollow after sawteeth stop
- current profile becomes hollow and an n=1 mode grows until it triggers the MGI.

➔ **Early detection of radiation peaking**

choice of alarm level:
*too early* vs. *too late*
work in progress …



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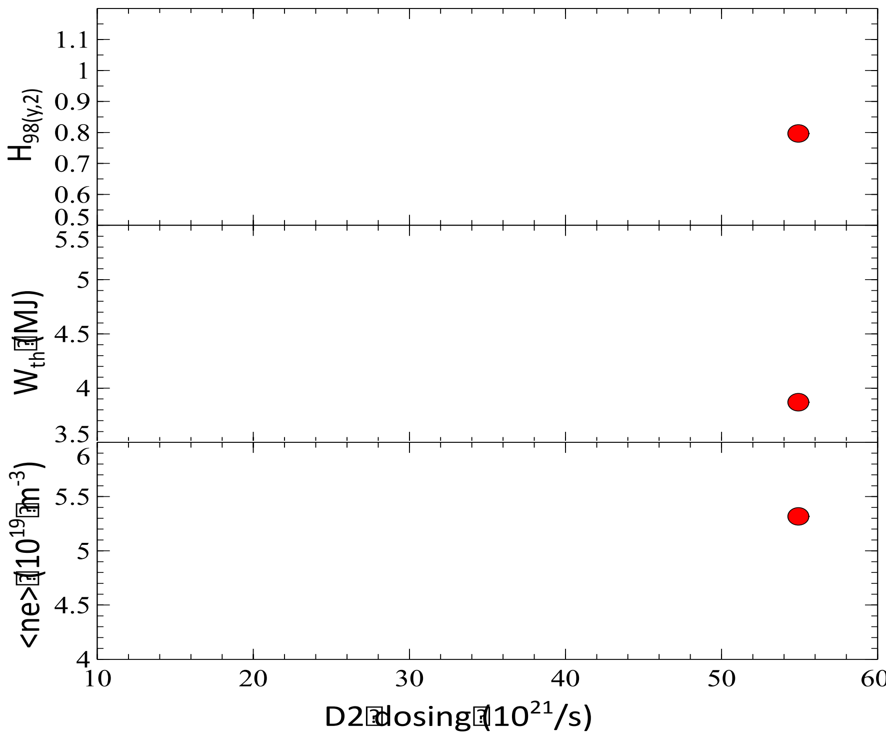
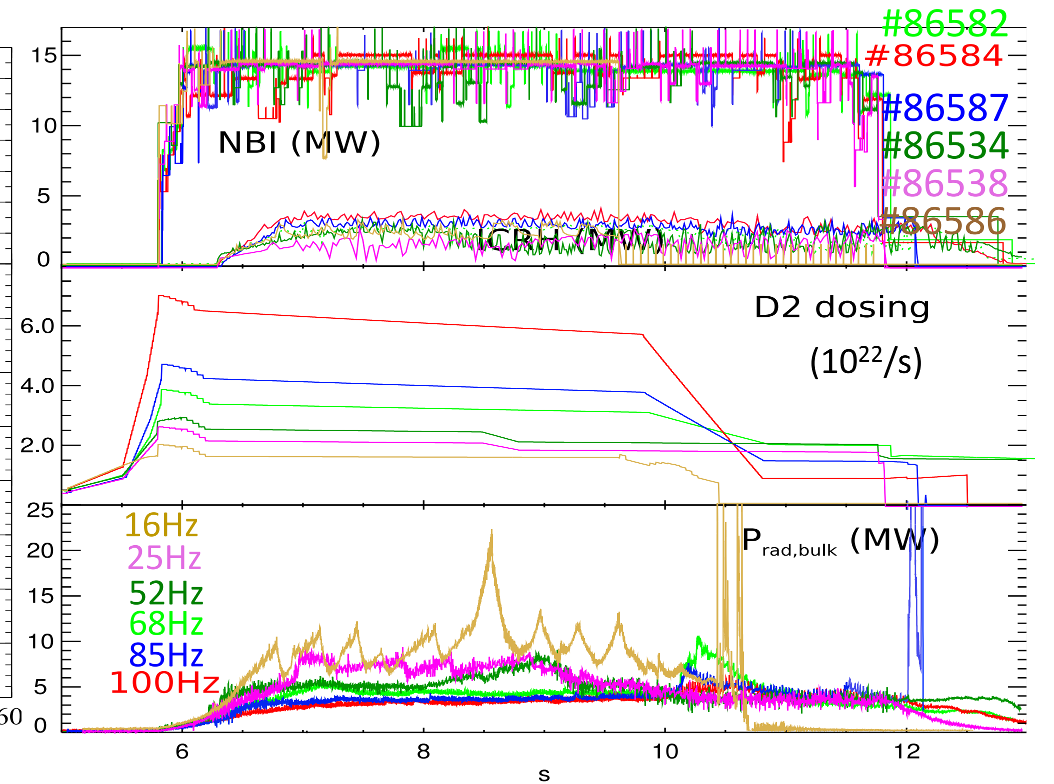
# Control of W accumulation – gas

## Gas puffing

- Increases ELM frequency to control W reaching the plasma core
- Stationary discharges although at reduced confinement

2.5MA/2.35T



# Control of W accumulation - ICRH

- **ICRH heating →** increases core electron temperature and maintain sawteeth activity → expel W from core

E Lerche EX/P5-22

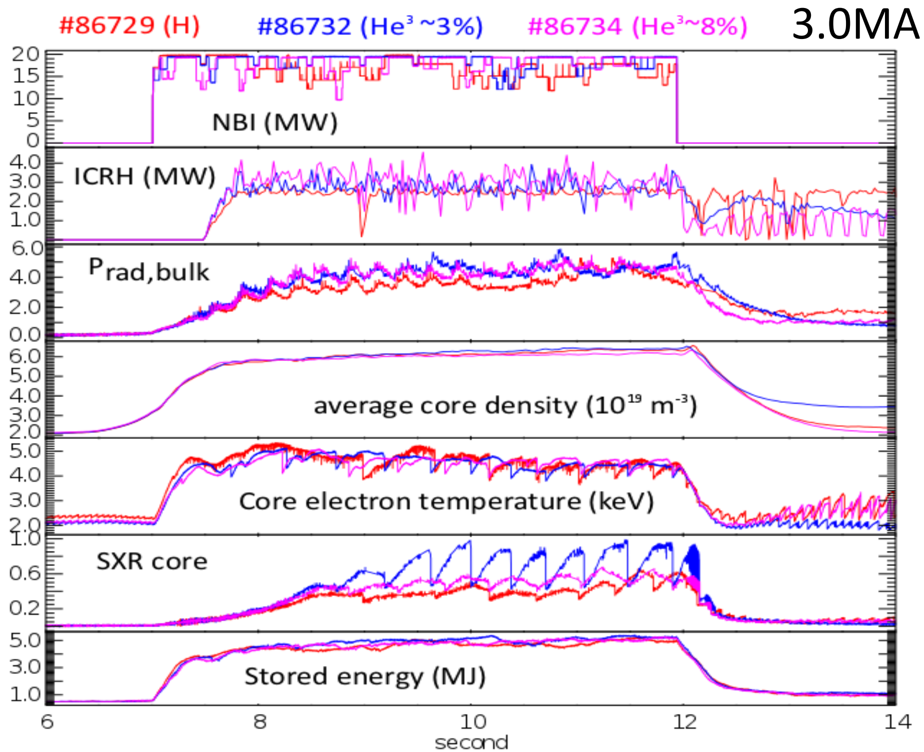
**RF frequencies ↔ $B_T$ constraints ($q_{95}$=3)**

**H minority off-axis**

- Effective if resonance inside q=1 surface

**He3 minority on-axis**

- Similar results to H minority (off-axis, inside q=1 surface) at ~8% $He^3$ concentration → small impact on performance



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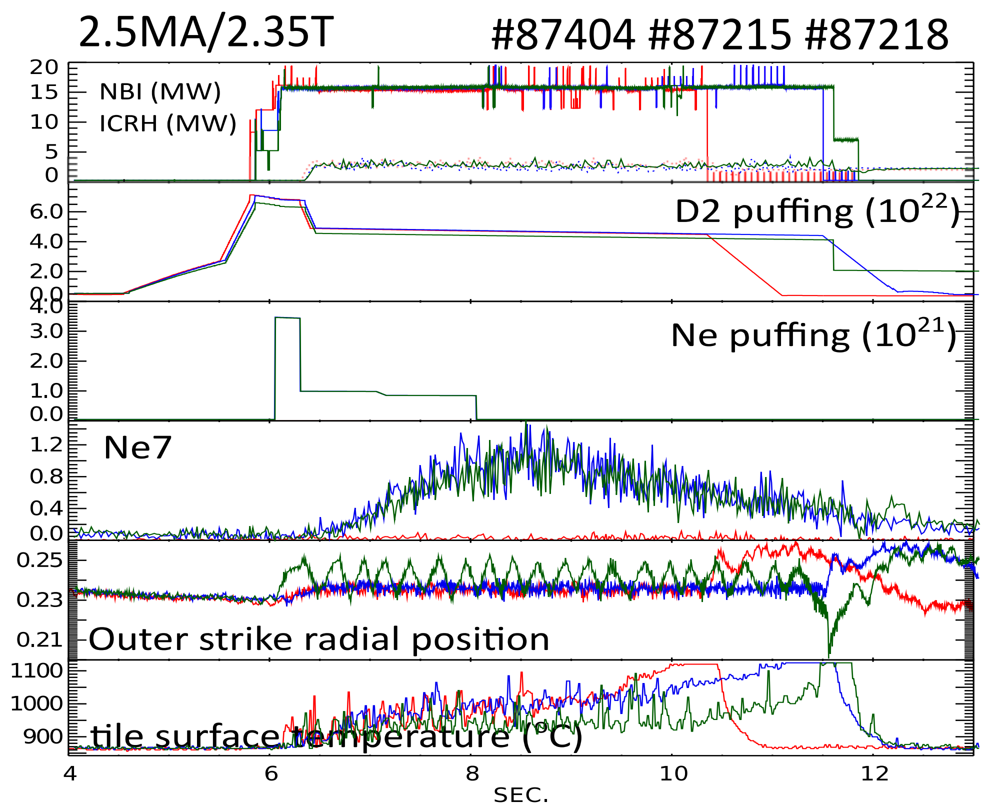
**JET has restrictive operation limits for bulk W and W coated CFC tiles ➔ pulse length at high power at high plasma current**

**Extrinsic impurities**

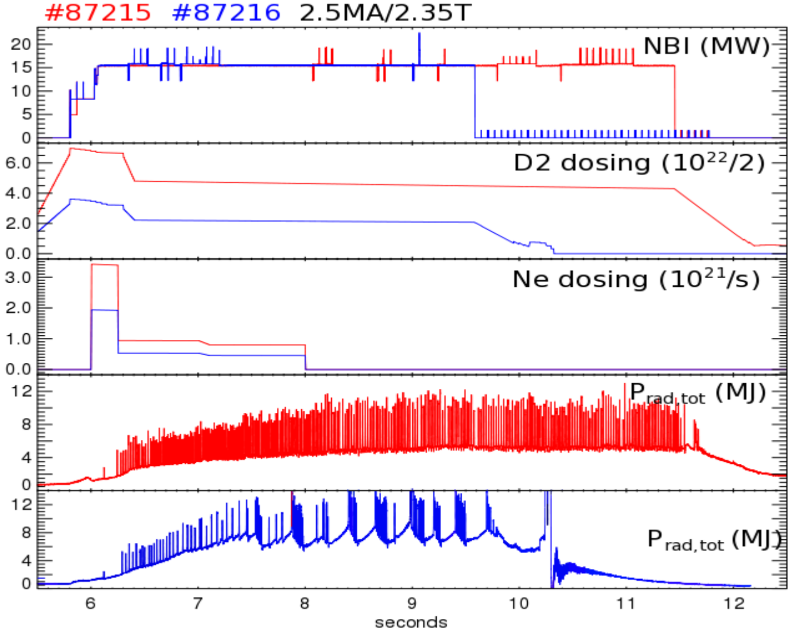
- N2 not compatible with DT operation → Tritium plant at JET
- Ne: Small reduction of target surface temperature

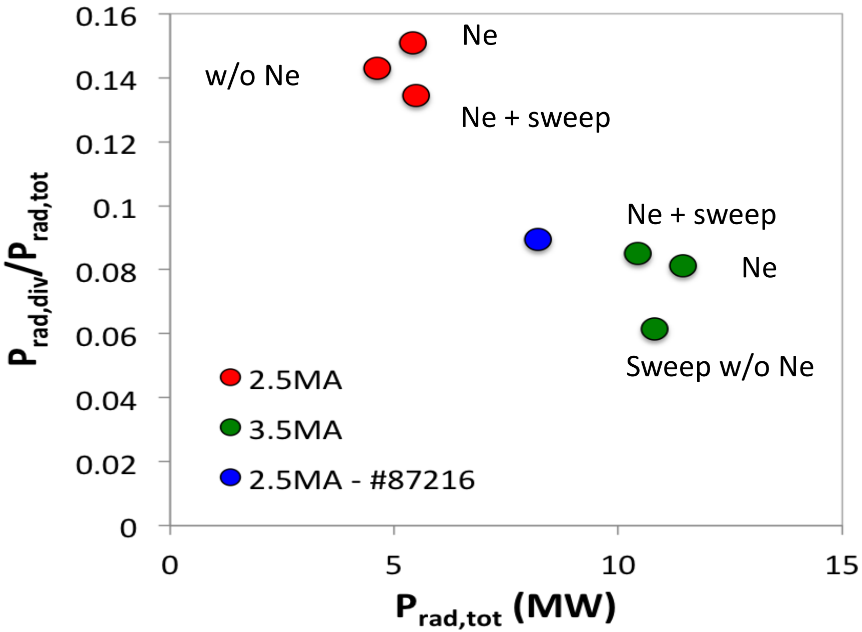
**Strike point sweeping at 4Hz**

- 4cm sweeping → strong reduction of surface target temperature



# Divertor heat load control – Ne




- Range of D2/Ne narrow →transitions to ELM-free followed by type III ELMs
- Small change $P_{radDIV}/P_{rad,TOT}$ with Ne injection →observations of small reduction of target surface temperature
- Experiments at 3.5MA show no increase of $P_{rad,div}$

C Giroud Ex/P5-25

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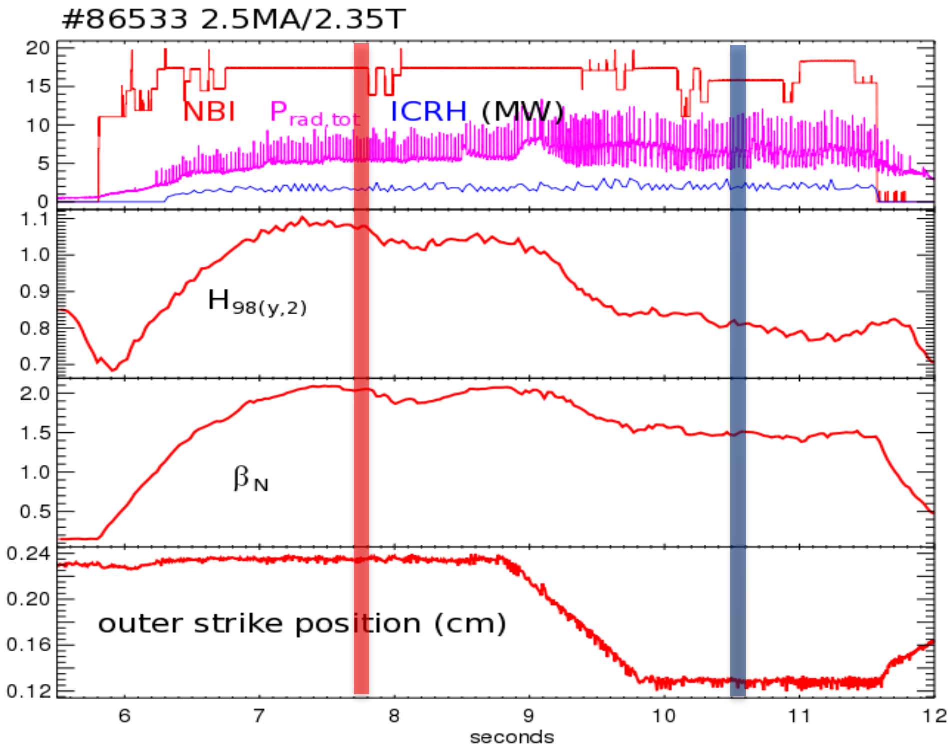
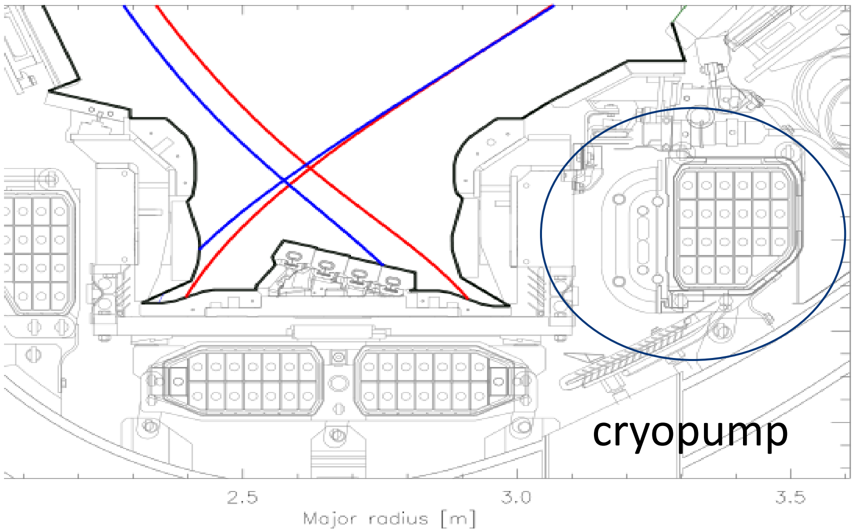
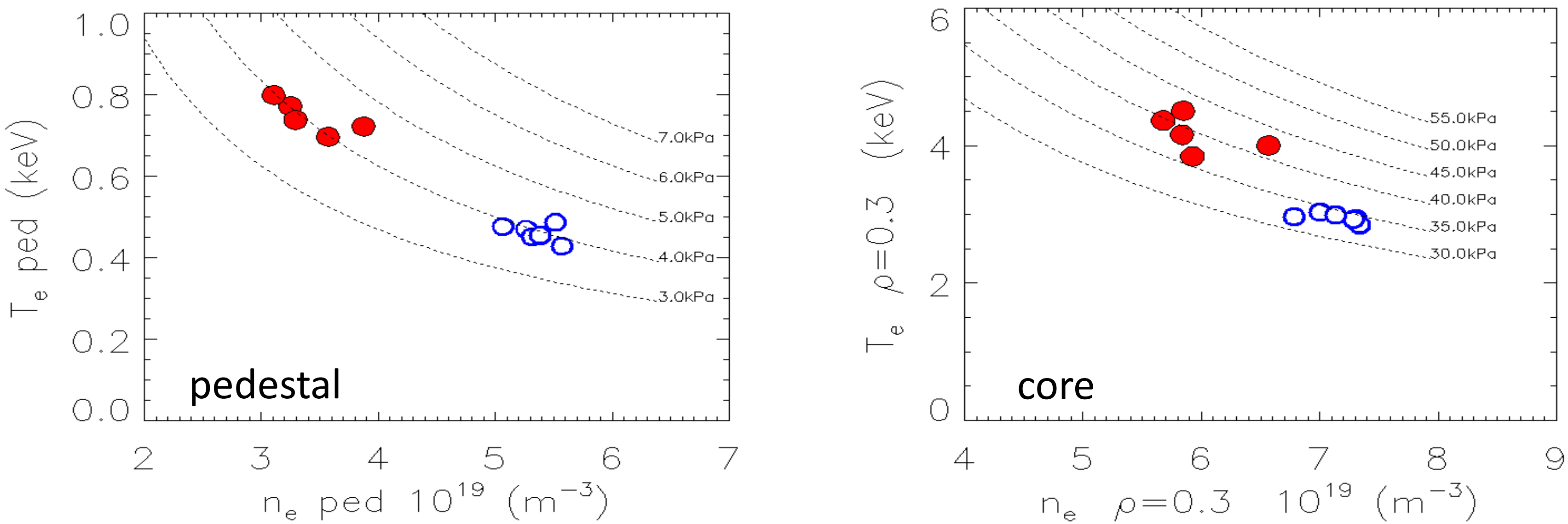
# Confinement (strike point position)

- Strike points close to pump throat
  - operate at lower pedestal density ➔ higher pedestal temperature
- As a consequence confinement improves (still need for gas puffing)



# Pedestal and core behaviour

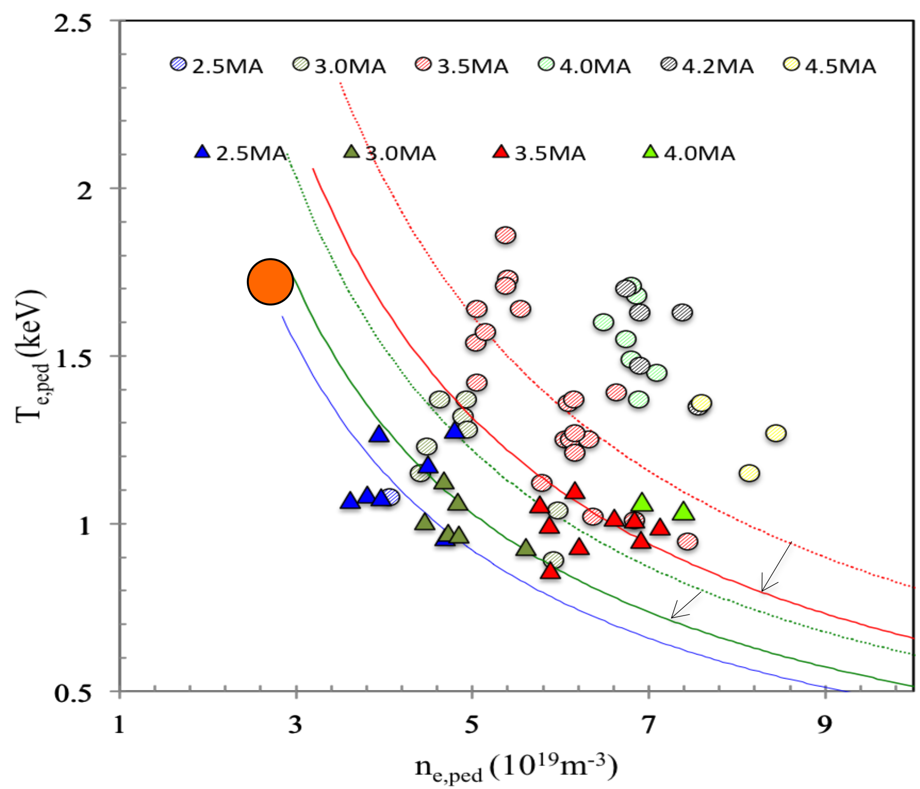



- **Pedestal** - Similar pedestal pressure but higher pedestal temperature when strike points closer to pump throat
- **Core** - higher density peaking due to lower collisionality → higher core pressure

E de la Luna EX/P5-29 E Joffrin EX/P5-40 C Maggi EX/3-3

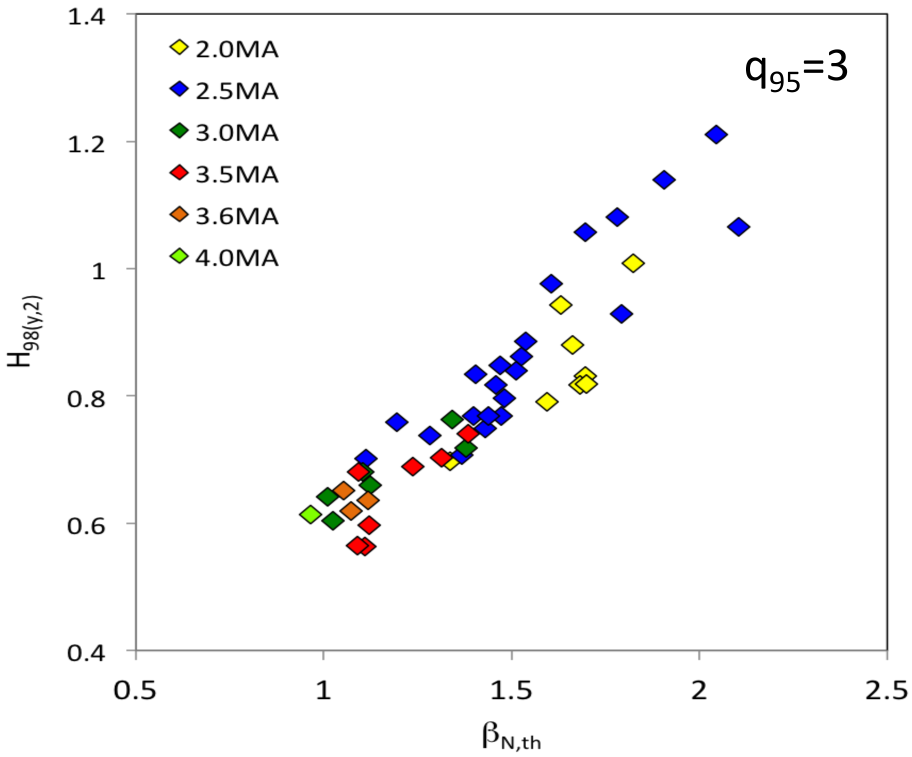
# Pedestal behaviour for increasing $I_p$

- JET-C: both $T_{e,ped}$ and $n_{e.ped}$ increase with $I_p$
- Density similar to JET-C but $T_{eped}$, below ~1.2keV for $I_p$>2.5MA
- At similar $I_p/B_T$ the pedestal pressure is considerable lower than that on CFC
- Hybrid scenario shows that with high $P_{add}$ is possible to get higher $T_{e,ped}$ → higher confinement



# Confinement dependence on $P_{IN}$

- $H_{98(y,2)}$ is seen to strongly increase for $\beta_{N,th}$ above ~1.6 with a fast rise of the pedestal pressure, mainly due to the increase of the pedestal temperature

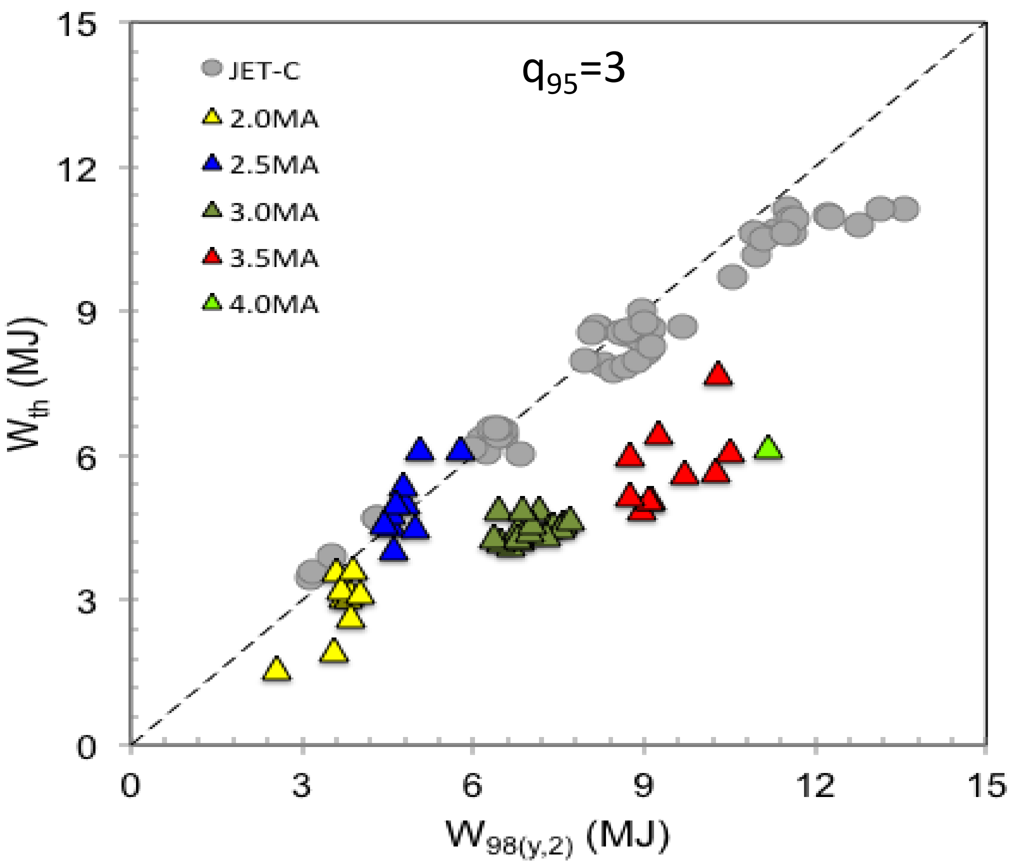



C Challis EX/9-3

- Achievement of good confinement at high $I_p/B_T$ strongly dependent on power (and gas dosing)

# Summary

- Optimised plasma termination and the detection of off-normal events
- Used gas dosing and ICRH to control W accumulation
- Optimised confinement by increasing pedestal temperature
- Achieved $H_{98(y,2)}$~1 at 2.5MA (like JET-C)
- Achieved stationary conditions up to 4MA/3.73T ($P_{TOT}$=27MW)



# Prospects

- Further optimisation is a primary goal for 2015/2016 campaigns
  - Higher available additional power 32MW NBI + ~10MW RF
  - Reduce gas dosing
- Explore other extrinsic impurities for divertor heat load control
- Minimise gas fuelling to improve confinement by introducing fuelling with pellets