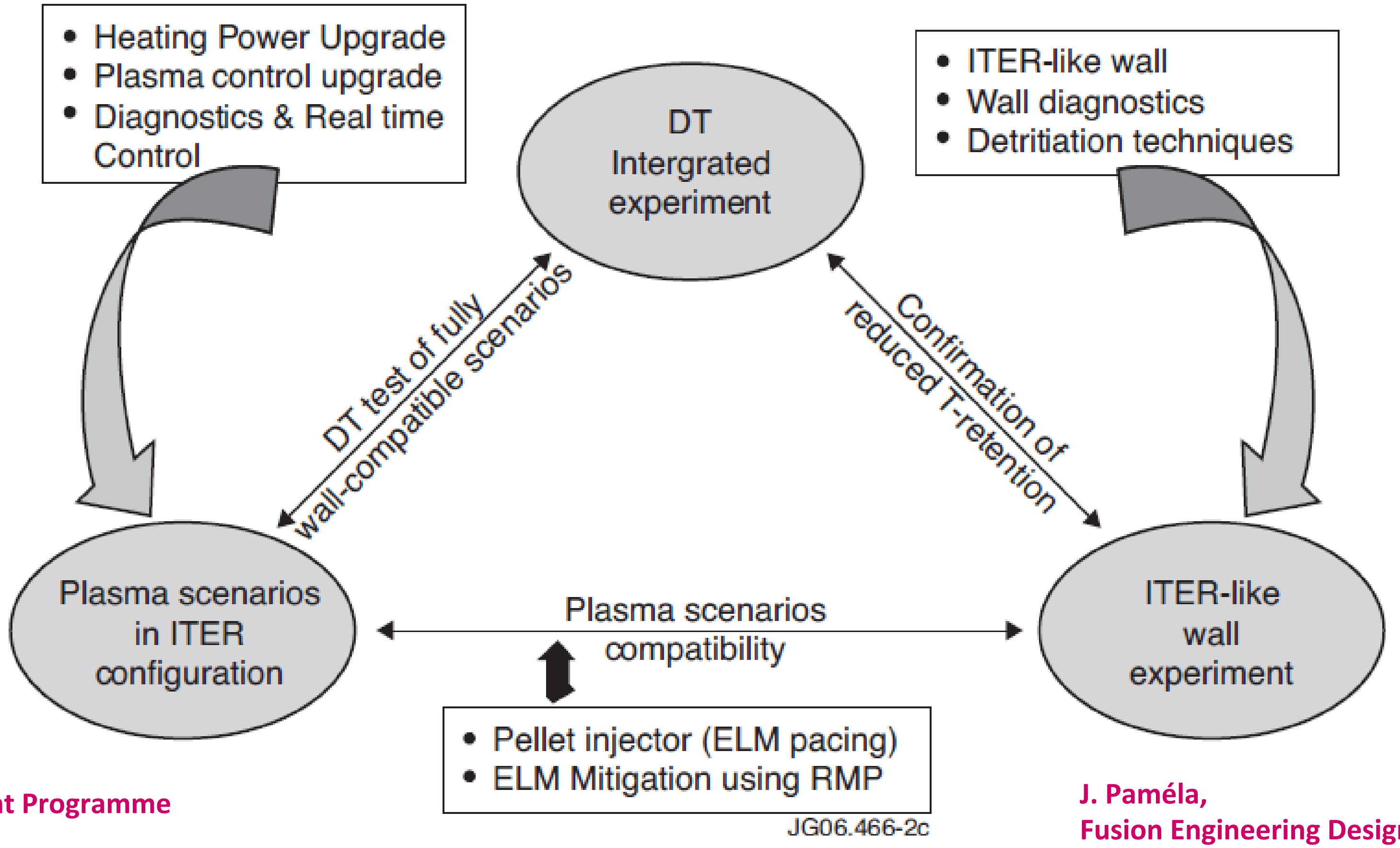
Overview of the JET 2013 Work Programme

Isabel Nunes
Deputy TFL for E1

Context for the JET Campaigns



EP2 Enhancement Programme

J. Paméla,
Fusion Engineering Design, 2007

Coherent approach in a multi-annual "JET programme in support of ITER" based on the full exploitation of the ILW

Phase I: Experimentation with an ITER-like-Wall (2011-2012)

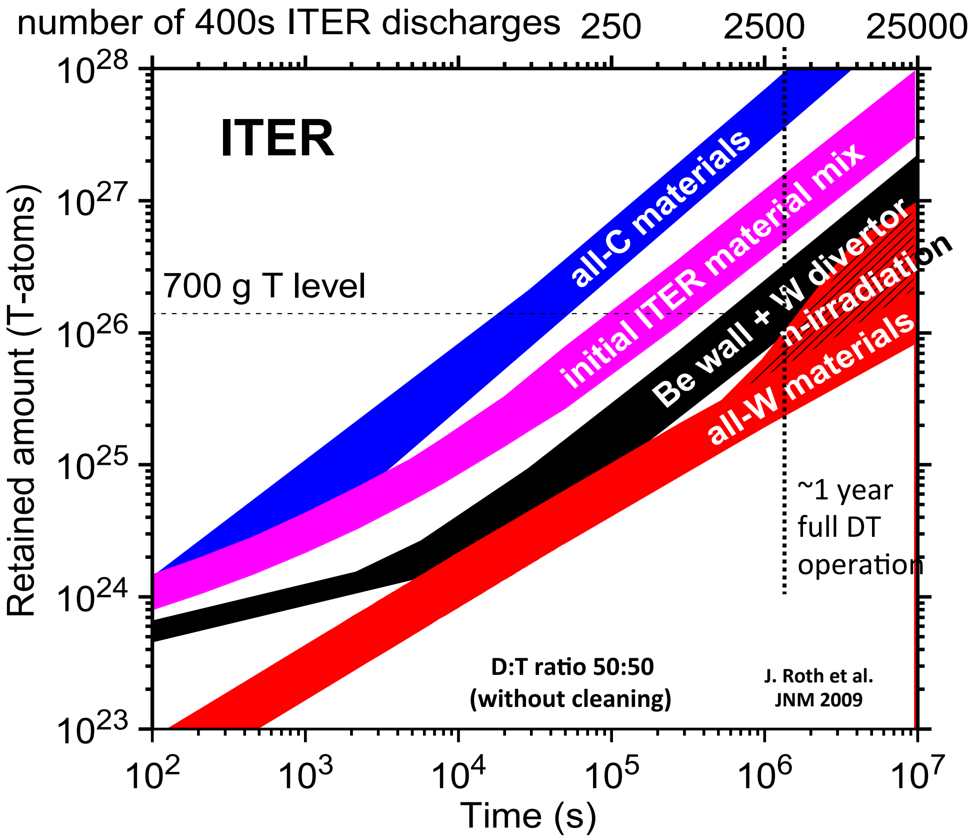
Phase II: Develop plasma scenarios approaching ITER relevant conditions (2013-2014)

Phase III: Integrated experimentation in deuterium-tritium (2015)

Outline

- The ITER-like Wall at JET
- Upgrades/Protection to operate a Be/W machine
- Results from 2012 operation
- Planned strategy for 2013

ITER Predictions: Reduction in Fuel Retention with Change of First Wall



J. Roth, S. Brezinsek

- Critical issues: safety and lifetime or fuel retention and first wall erosion
- Predictions made from CFC devices, laboratory experiments and modelling

Reduction to of a factor 10-50 expected!
Note: limit recently increased to 1kg T

Plasma-Wall Interaction Issues

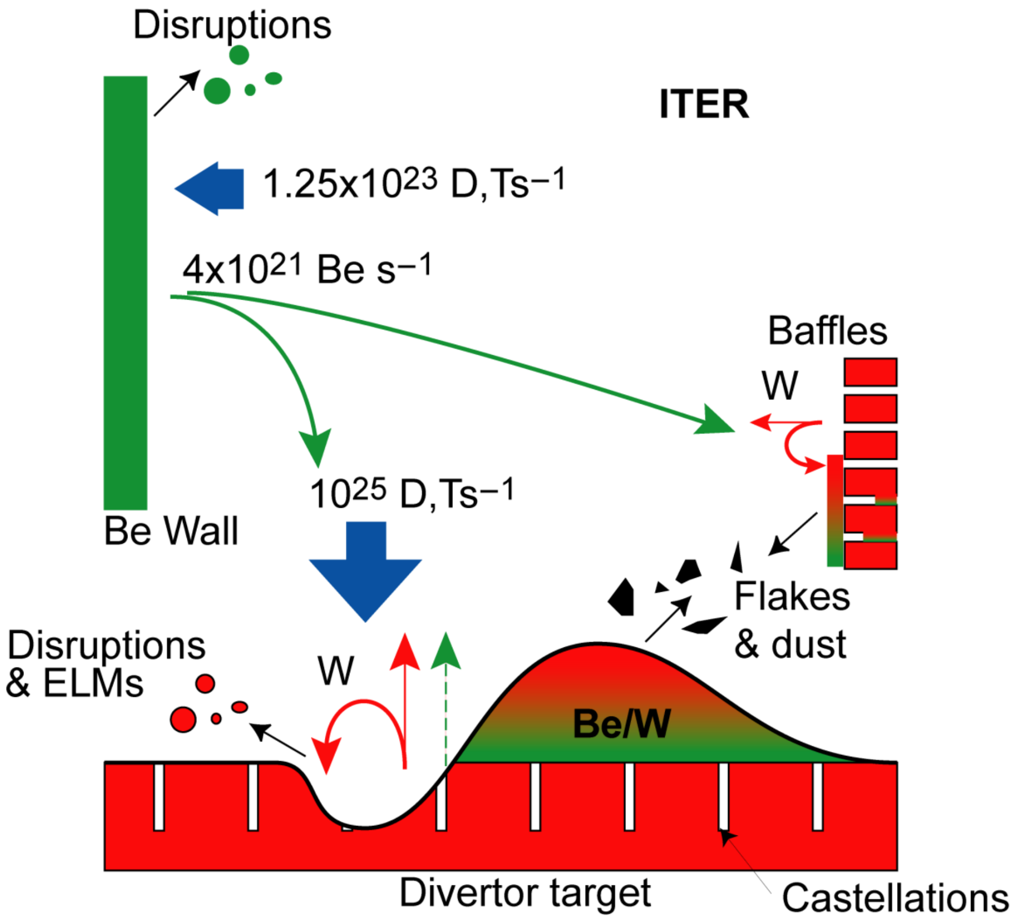
Important PWI questions for ITER will be addressed in JET with the ILW

Steady-state operation

- Be wall erosion and transport
- Be-W material mixing
- Be:D layer formation and retention
- Re-erosion of (mixed) layers
- Material Transport to remote areas
- W erosion and prompt deposition

Transients

- Be/W Melt layer motion, loss and stability
- Metallic dust formation



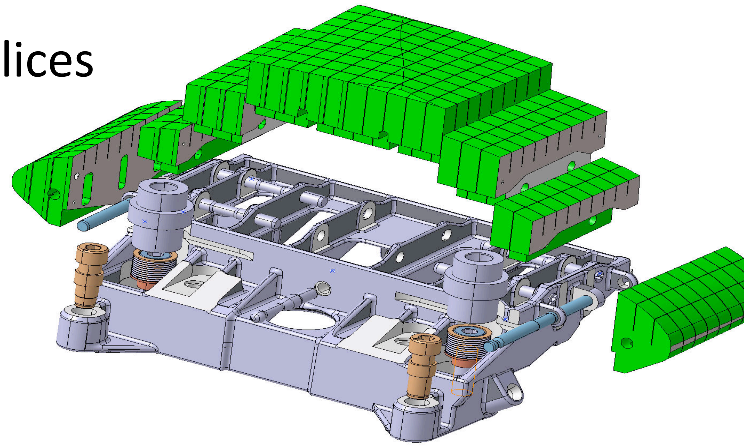
G Matthews, S. Brezinsek

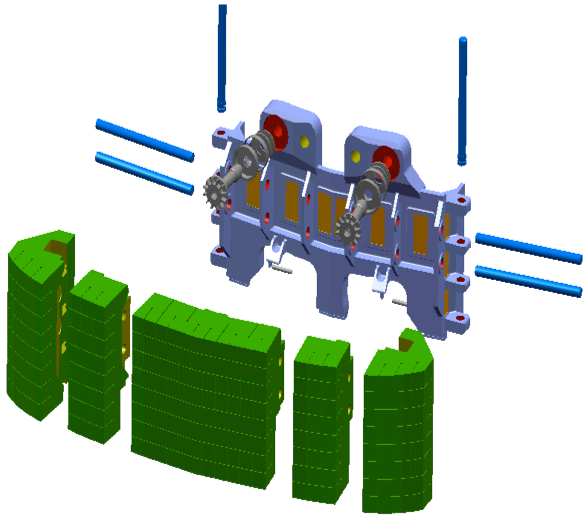
G. Matthews

Material constraints

Be main chamber limiters

- Risk factor: melting ~1240°C
- Eddy forces → castelations
- Thermal stress → slices

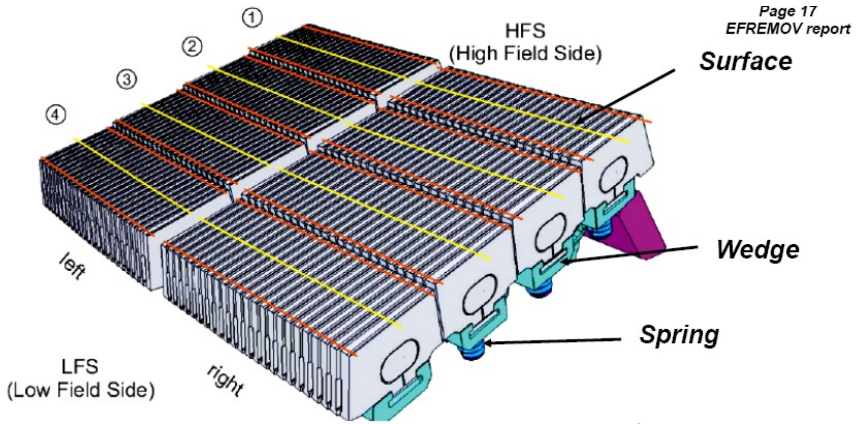




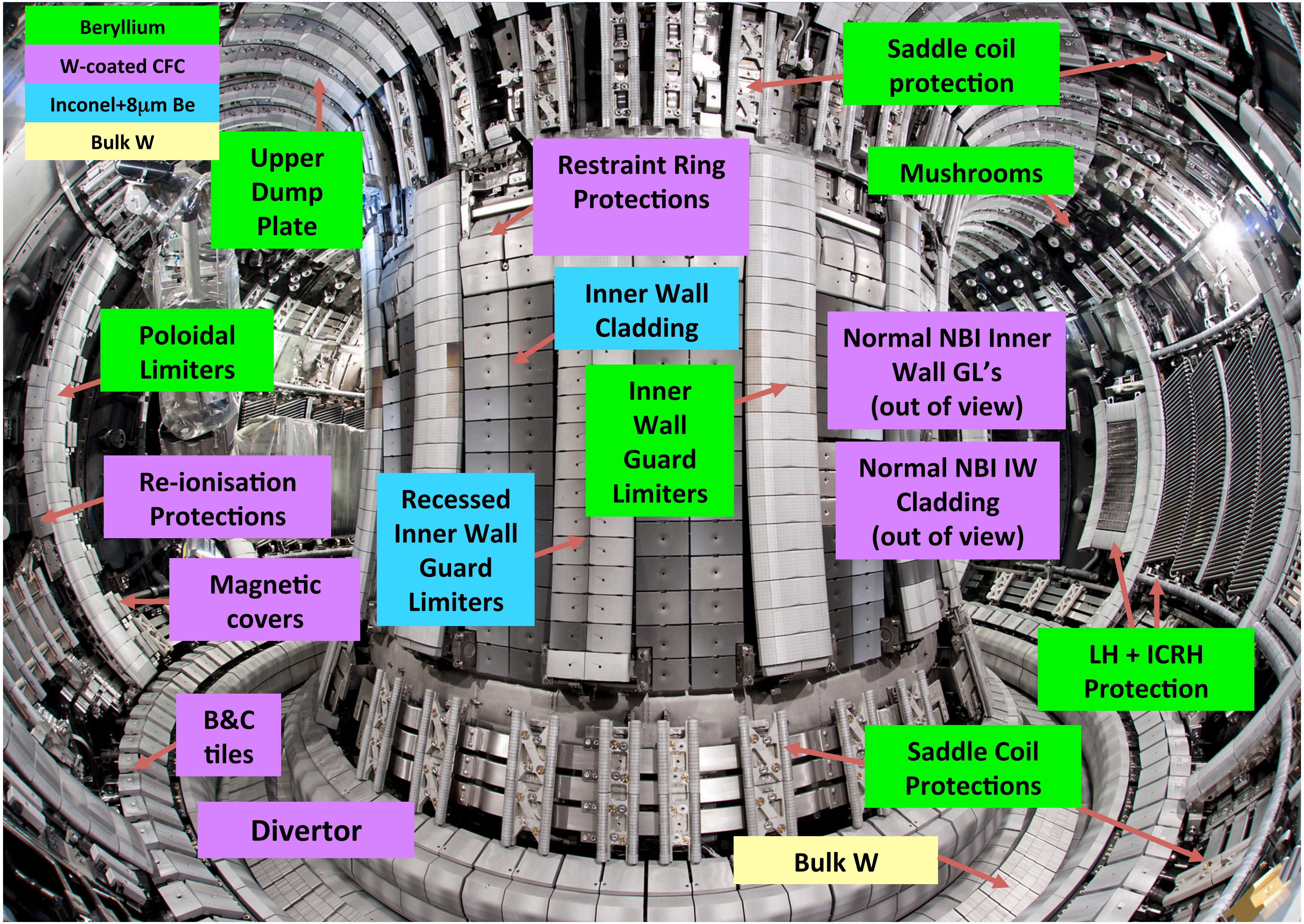
I. Nunes, P. de Vries, P. Lomas

Bulk W LBSRP

- Surface temperature limit: initially 1200°C (avoid recrystallisation), later 2200°C
- Wedge temperature (600°C, or 72 MJ/m²)
- Springs (under investigation, probably 350°C, or <60 MJ/m²)

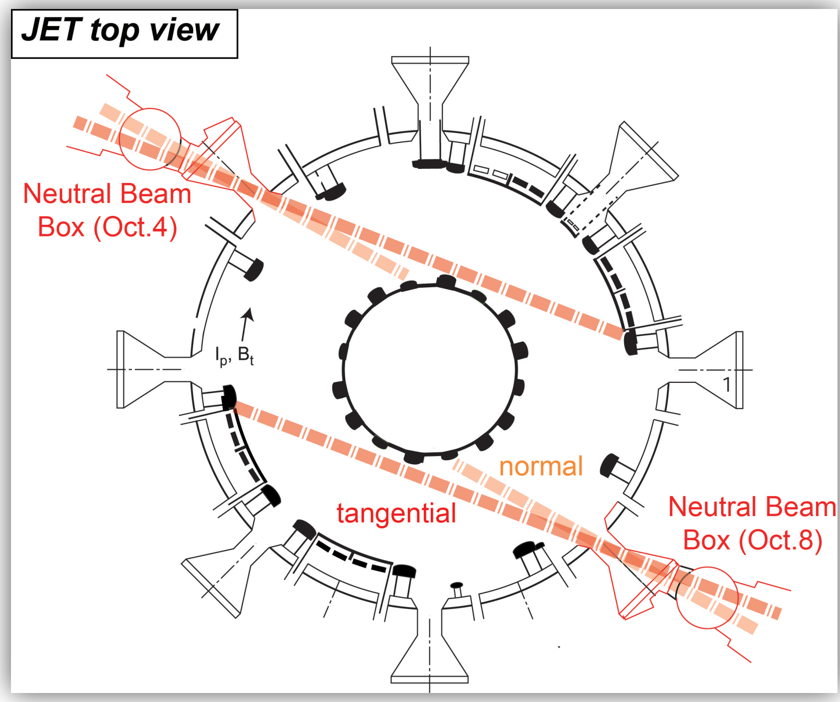


Ph. Mertens



ILW = 2880 installable items, 15828 tiles (~2 tonnes Be, ~2 tonnes W)

JET NBI system



[CIRIC et al., FED, 86, 2011]

- Two neutral beam injector boxes
- Each equipped with 8 Positive Ion Neutral Injectors: **PINIs** ➔ grouped into tangential and normal banks

View of the JET vessel from inside the new beam "duct"

- In parallel with ITER-like wall installation ➔ NBI system upgraded
  - 1st goal: Increase NBI power from **24MW to 34MW** ➔ PINIs converted to 125kV PINIs with modified ion source, accelerator configuration & refurbished power supplies
  - 2nd goal: Increase NBI **pulse duration** at full power from 10s to 20s ➔ beam duct changed to actively cooled beam duct

Active protection for ILW (I)

Three systems monitor the wall loads in real time; the wall load limiter system (WALLS) [15], the plant enable window system (PEWS) and the new system, the vessel temperature map (VTM).

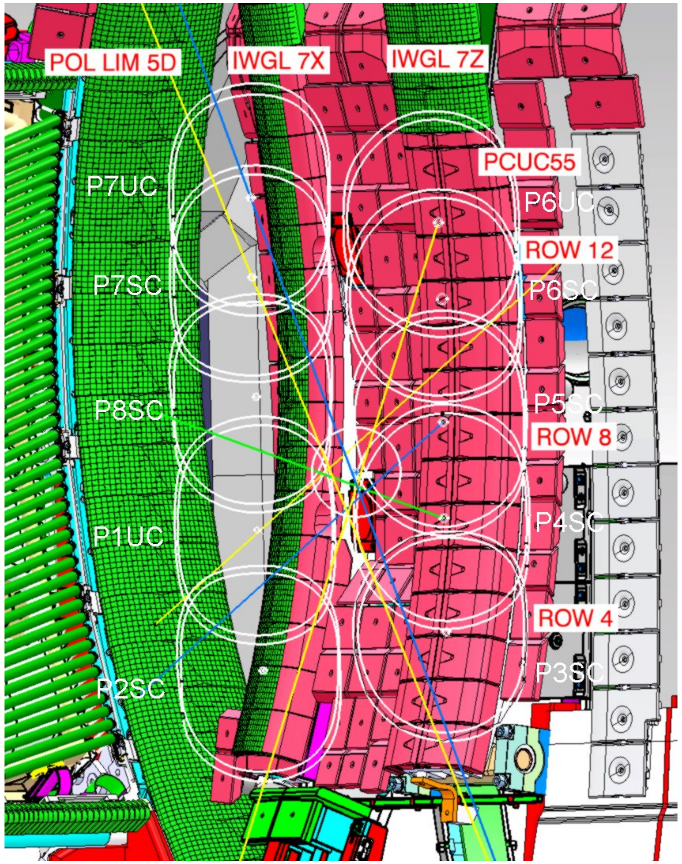
WALLS:

- Determines and controls the **topology and location of the plasma boundary** based on real-time magnetic measurements.
- **Models the power deposition and the thermal diffusion on individual plasma facing components** using the information of the plasma current and the instantaneous injected power, thus monitoring the surface and bulk temperatures of the PFCs.

PEWS:

- Predicts/protects the **surface temperature of shine through tiles** using RT density measurements and algorithm for temperature

PIW team

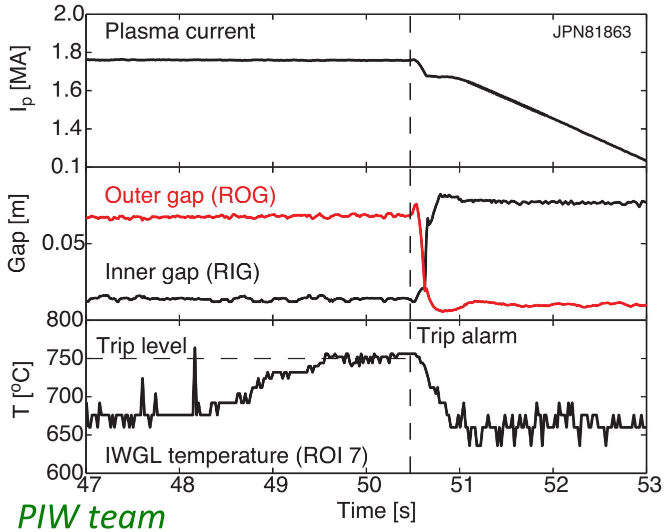


Inner wall NBI footprints

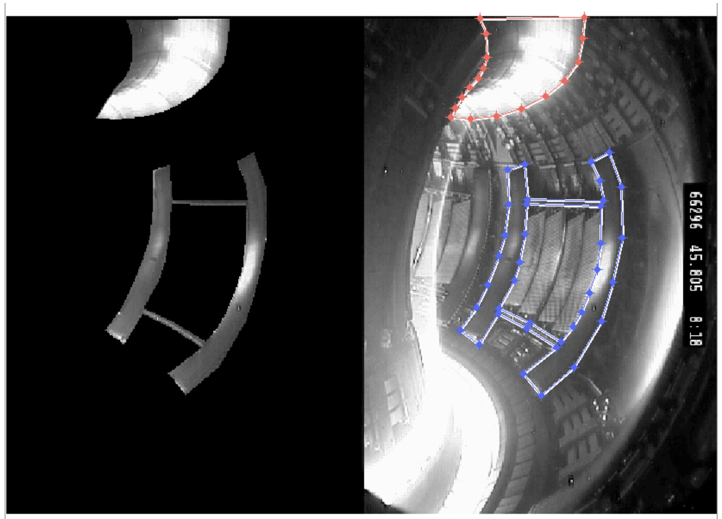
Active protection for ILW (II)

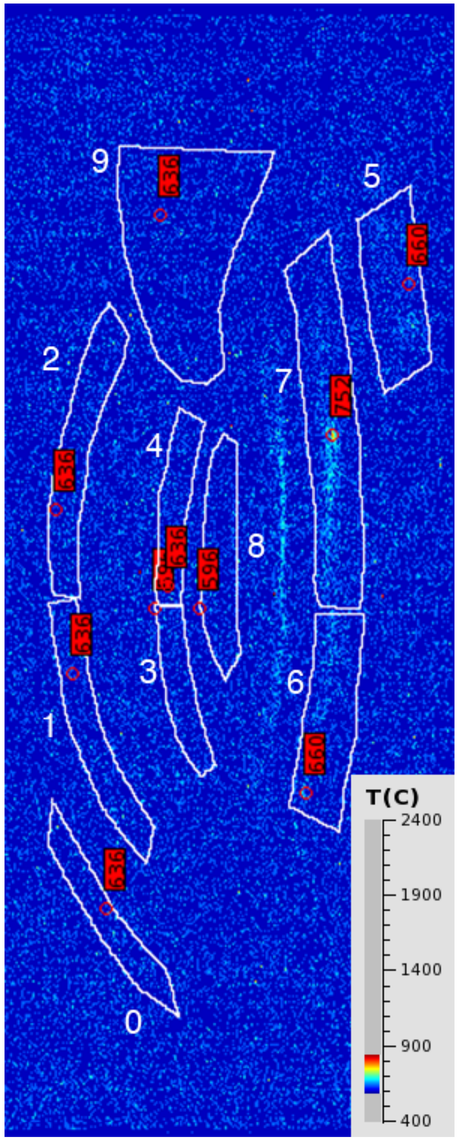
VTM

- Specifically designed to receive the data from the IR and near-IR cameras installed for the protection of the ILW.
- ROIs are analysed and its measured temperature processed in real-time
- Alarm issued to RTPS if any of the operating limits is reached
- RTPS co-ordinates the responses for various systems issuing a request for an action appropriate to the alarm



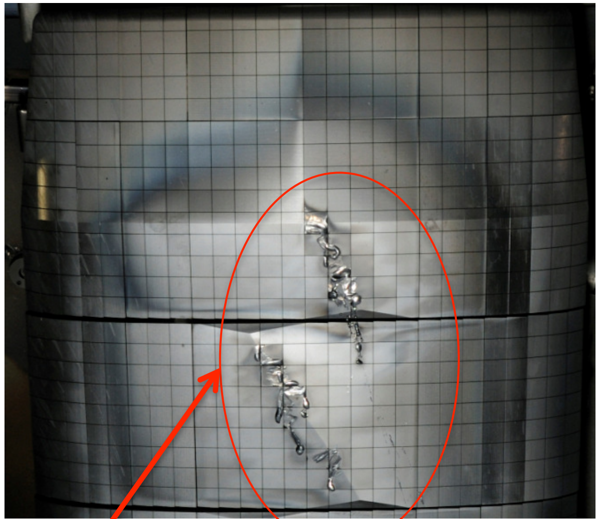
PIW team



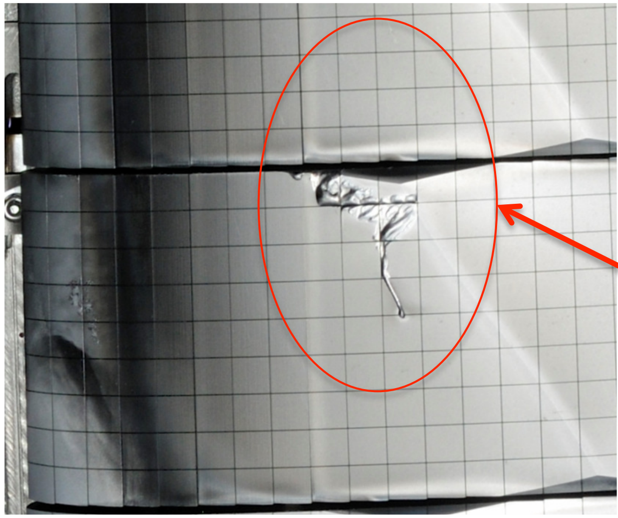


Melting

- Error on the temperature calibration of the protection cameras allowed temperatures > 1260°C on the tiles surface leading to melting



OWPL 6D top (B22122)



OWPL 7BR10 (A4L2533)

Langmuir probe

plasma load

Waiting for the first pulse with ITER-like Wall

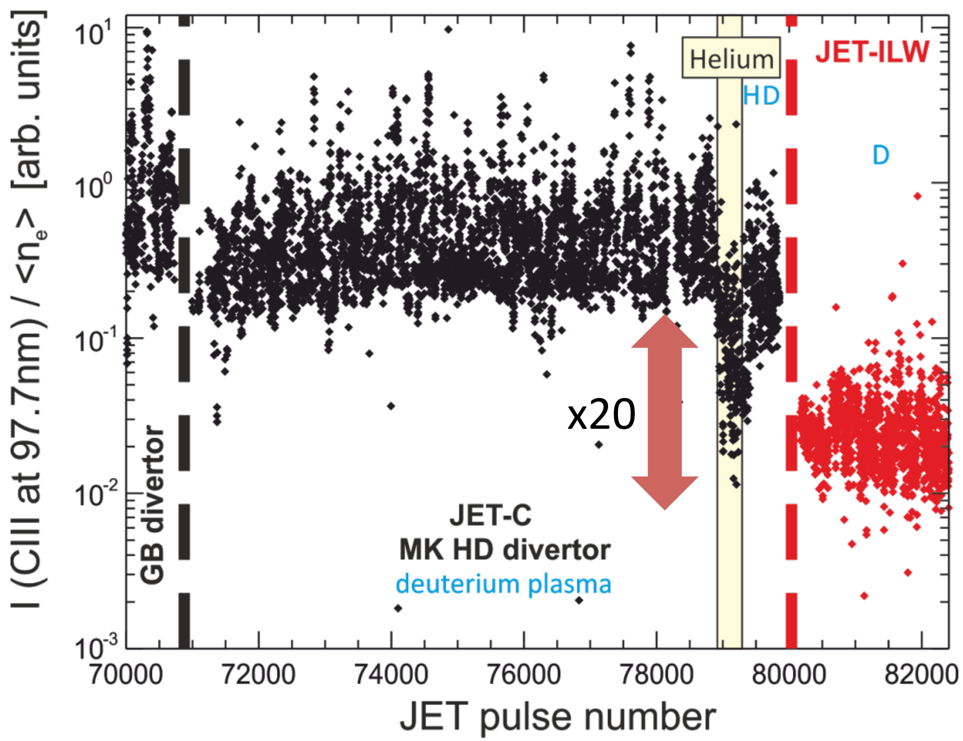
© CP11j-151-12

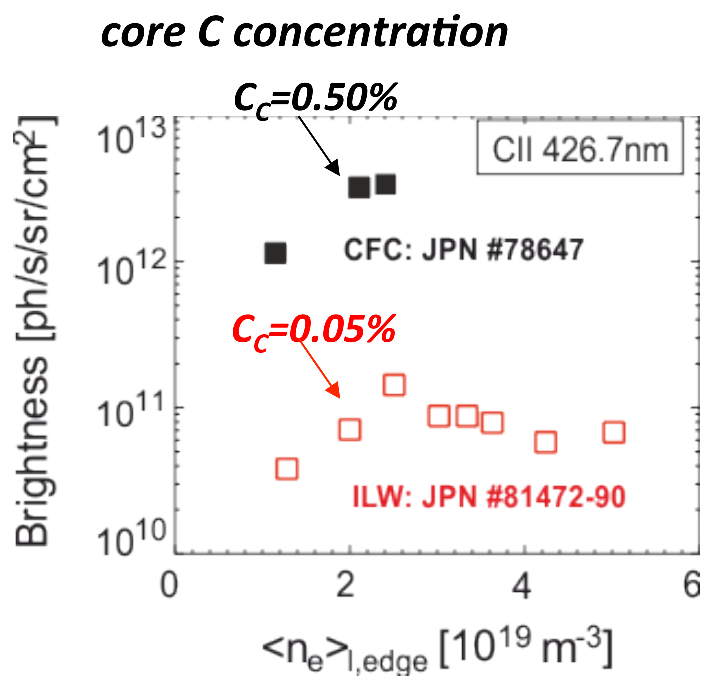
- Results from 2012 operation
  - Plasmas Surface Interaction
    - Fuel retention
    - W sources and transport
  - Plasma Physics
    - Breakdown
    - Disruptions
    - Pedestal and ELMs
    - Confinement
  - Operational issues
    - Plasma scenarios

Residual Carbon

Main chamber CIII and outer divertor CII edge fluxes:

- Residual **C dropped** with ILW installation **by one order of magnitude** (statistical)
- Dedicated JET-C/JET-ILW comparison pulses show a drop of about a factor 20



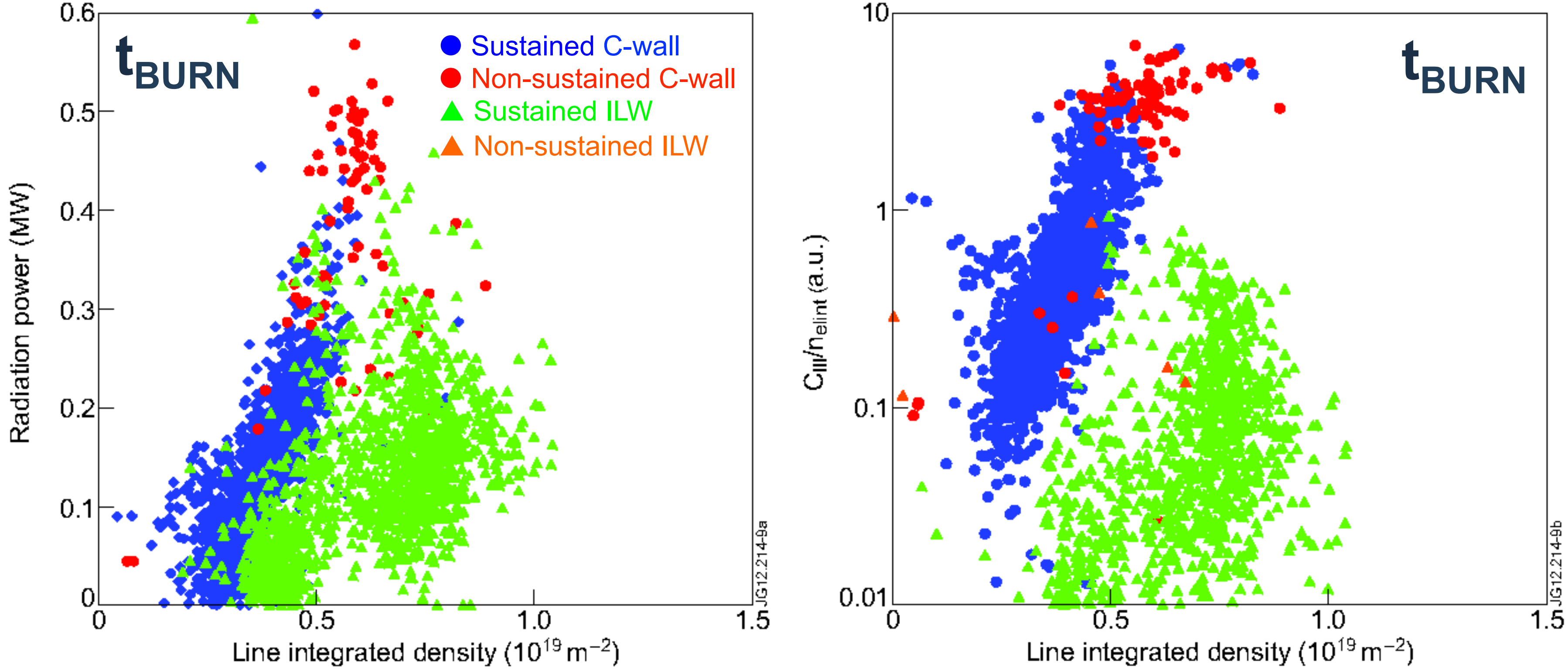


S. Brezinsek

- Comparable C reduction also observed in core and edge concentrations by CXRS
- Averaged Z_{eff} dropped from 1.9 (JET-C) to 1.2 (JET-ILW)

Breakdown

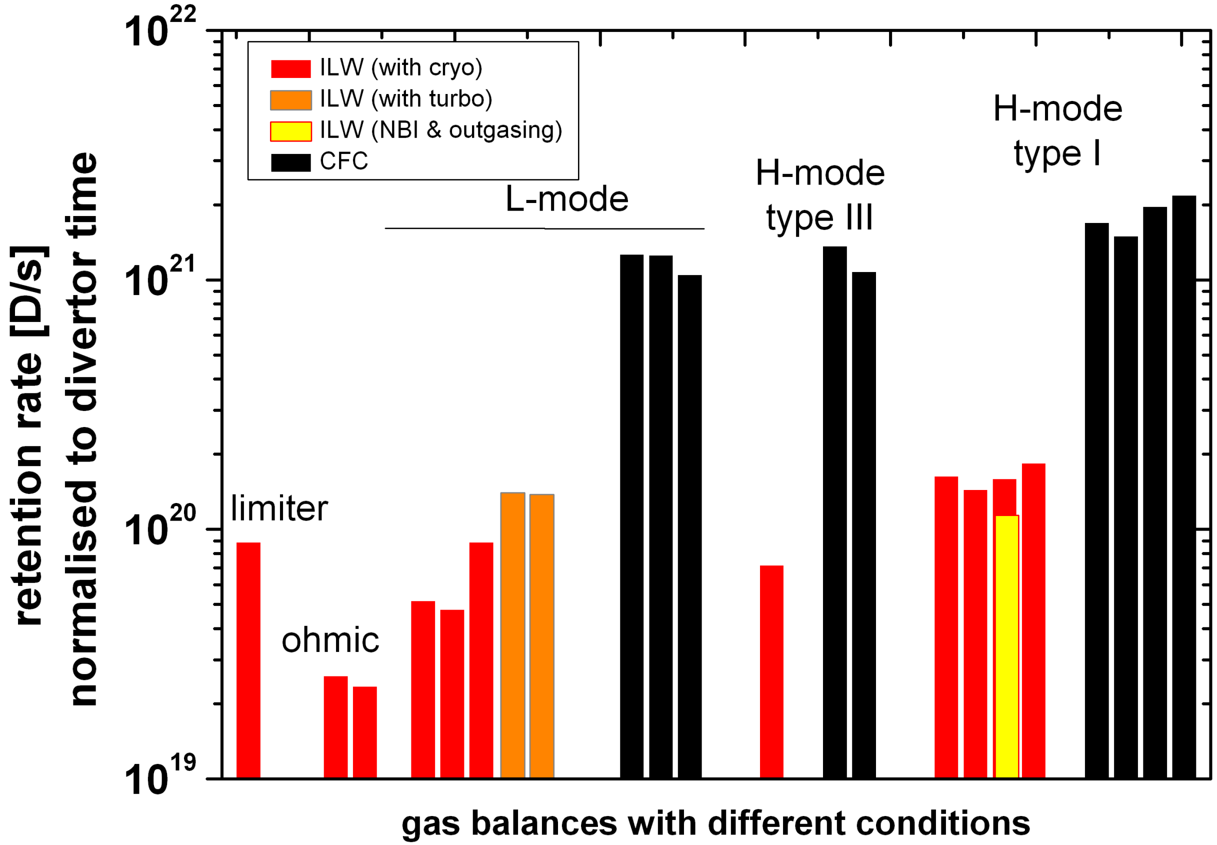
- For C-wall: relation between, density, *C* content and radiation
- For ILW: much lower radiation (and *C* content)
  - No non-sustained breakdowns due to de-conditioning events with ILW
  - Radiation lower (except for *N* seeding experiments)



- No trends were found with *O* or *Ne* levels

P. De Vries

Fuel Retention

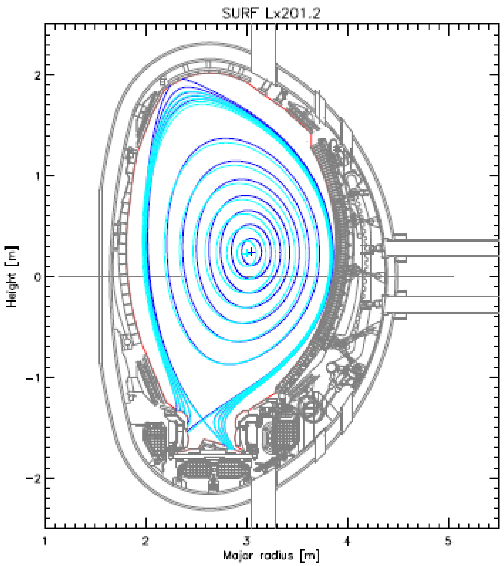


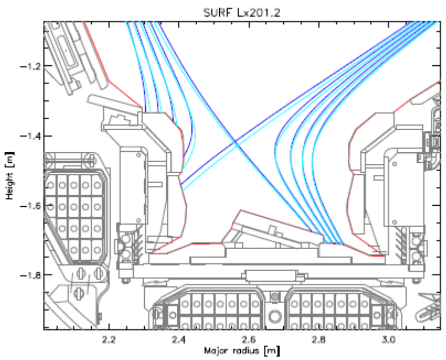
- Measured fuel retention is more than an order of magnitude lower with the ILW
- Consistent with predictions made before the installation of the ILW and with the model which is being applied to ITER

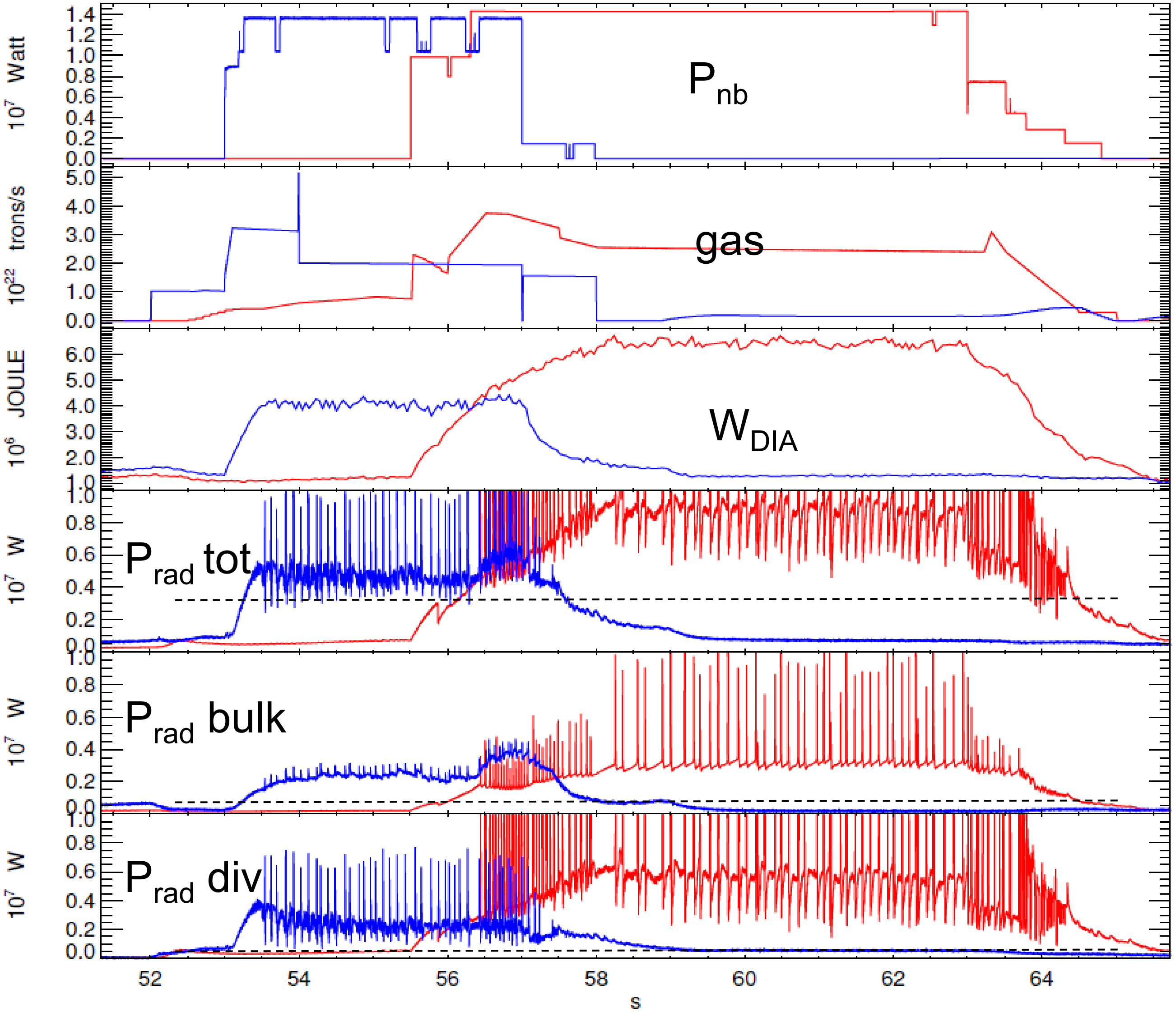
S. Brezinsek

Baseline scenario – CFC vs. ILW

73342 (CFC) vs. 82539 (ILW) @ 2.5MA/2.7T low delta



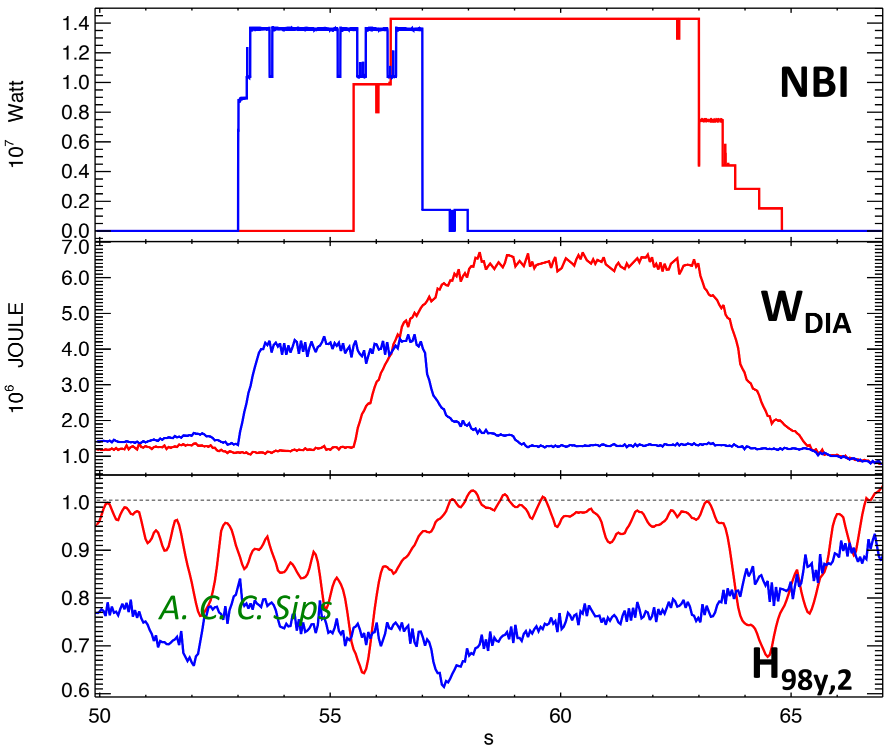


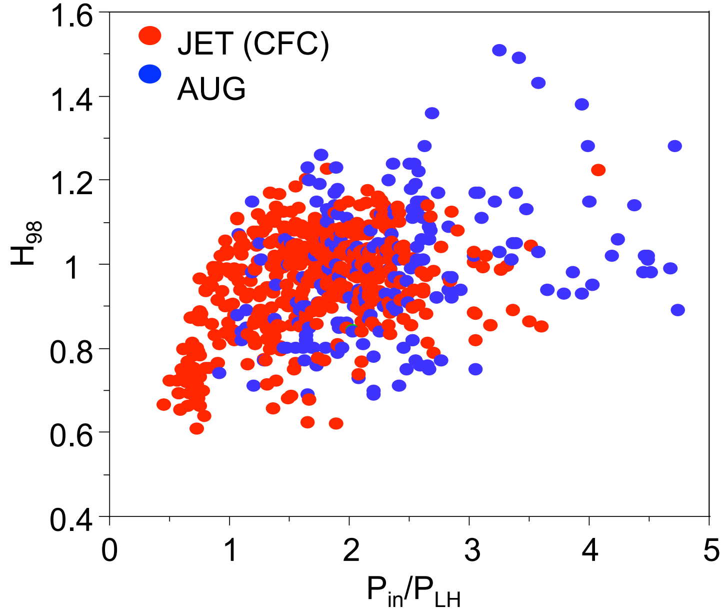


J. Bucalossi, E. Joffrin

Baseline scenario – CFC vs. ILW

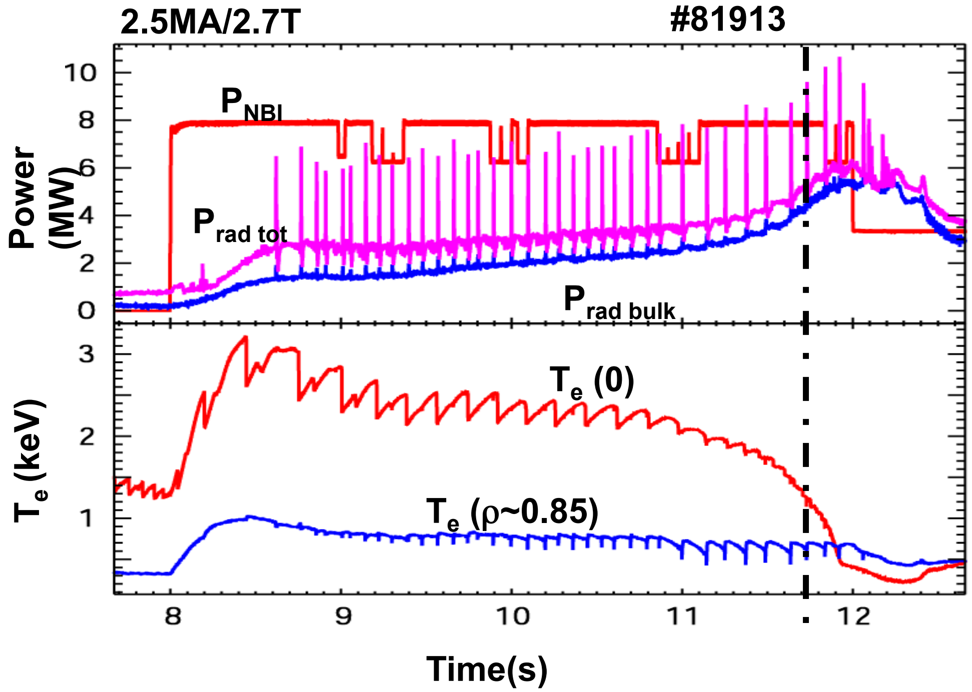
- Same scenario but ILW has:
  - lower stored energy
  - 20-30% lower confinement
- Both CFC and ILW have P_{IN}/P_{L-H}=1.5



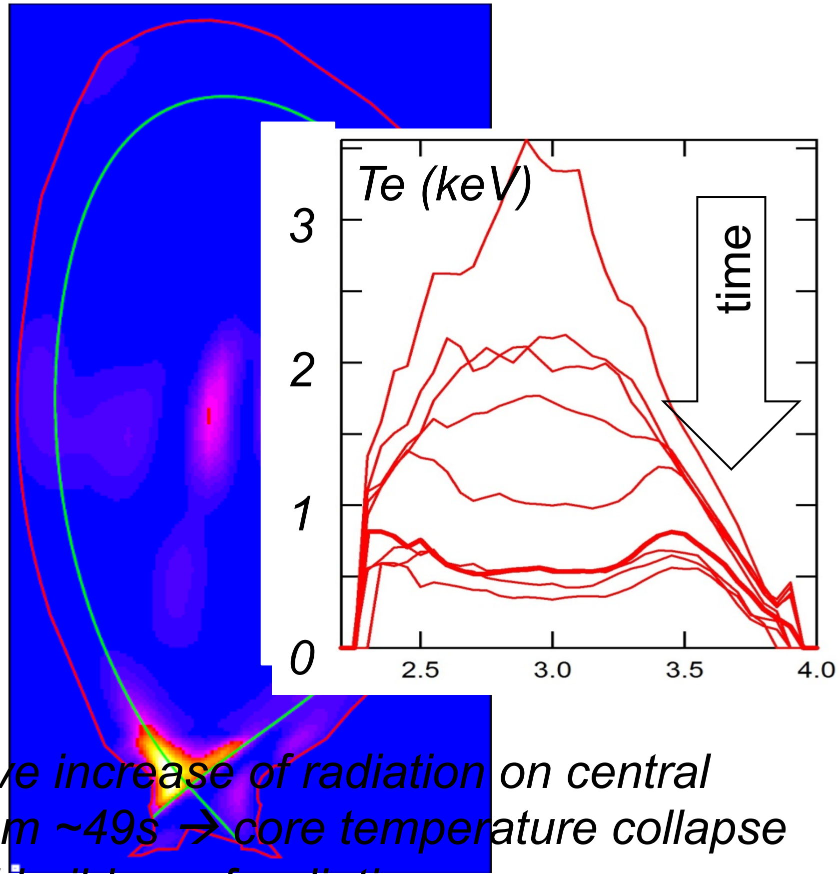


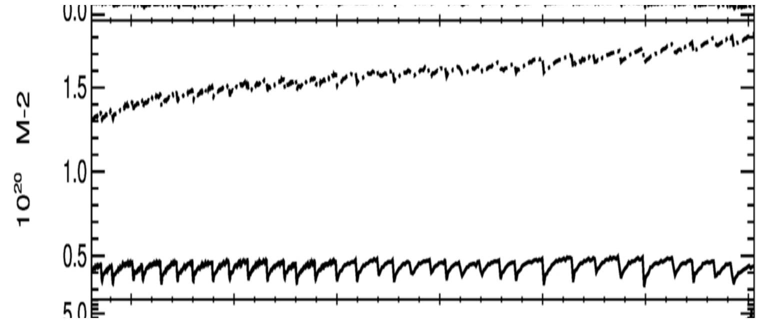
I_p [MA]	15	13.5	16.5
q_{95}	3	3.33	2.73
f_{GW}	0.85	0.85	0.85
n_e $x10^{20}$ [m^{-3}]	1.0	0.9	1.1
W_{th} change	1.0	0.8	1.26
β_N	1.8	1.6	2.06
P_{fus} [MW]	500	317	791
P_{in} [MW]	150	113	208
Q_{fus}	10	6.33	15.8
H_{98} to obtain P_{fus}= 500MW	1.0	1.15	0.88

Radiation in the core at low gas fuelling



Standard baseline scenario



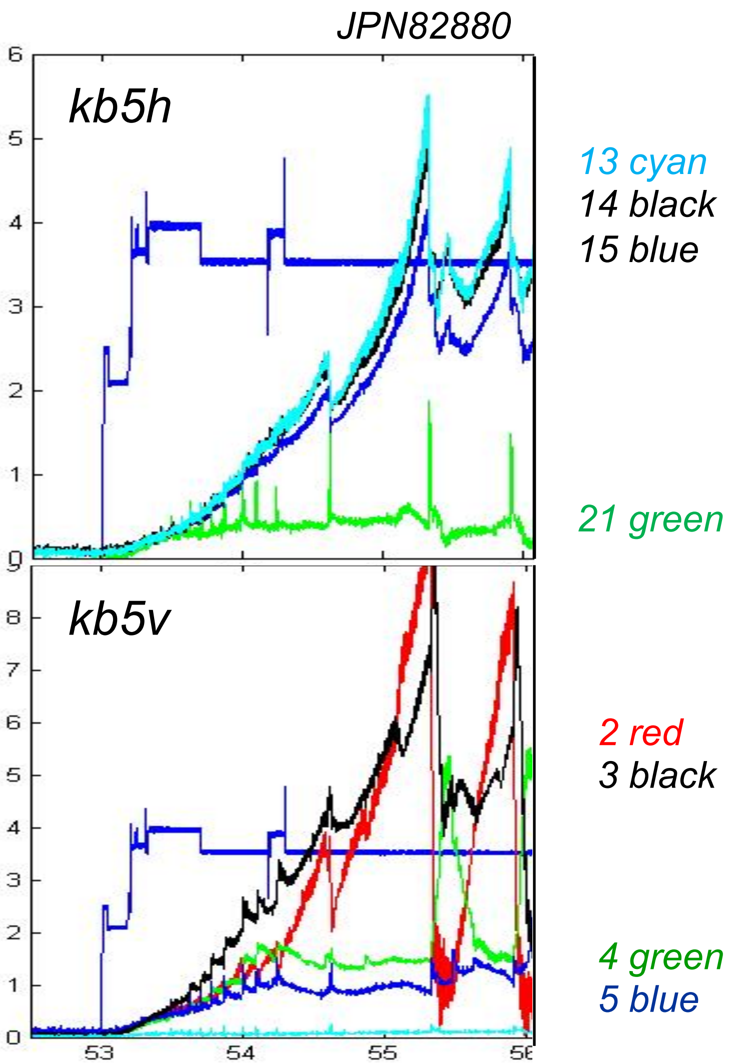


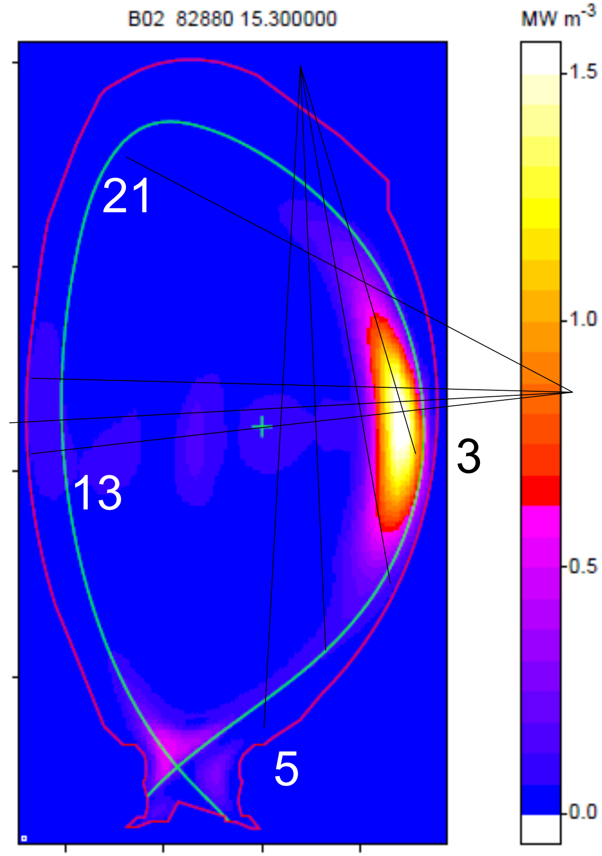
Progressive increase of radiation on central chords from ~49s → core temperature collapse ~51s, and build up of radiation

Edge radiation ~cte in time

T. Puetterich

Another example, with strong asymmetry





Radiative collapse prevented by increasing:

✓**Gas fuelling**

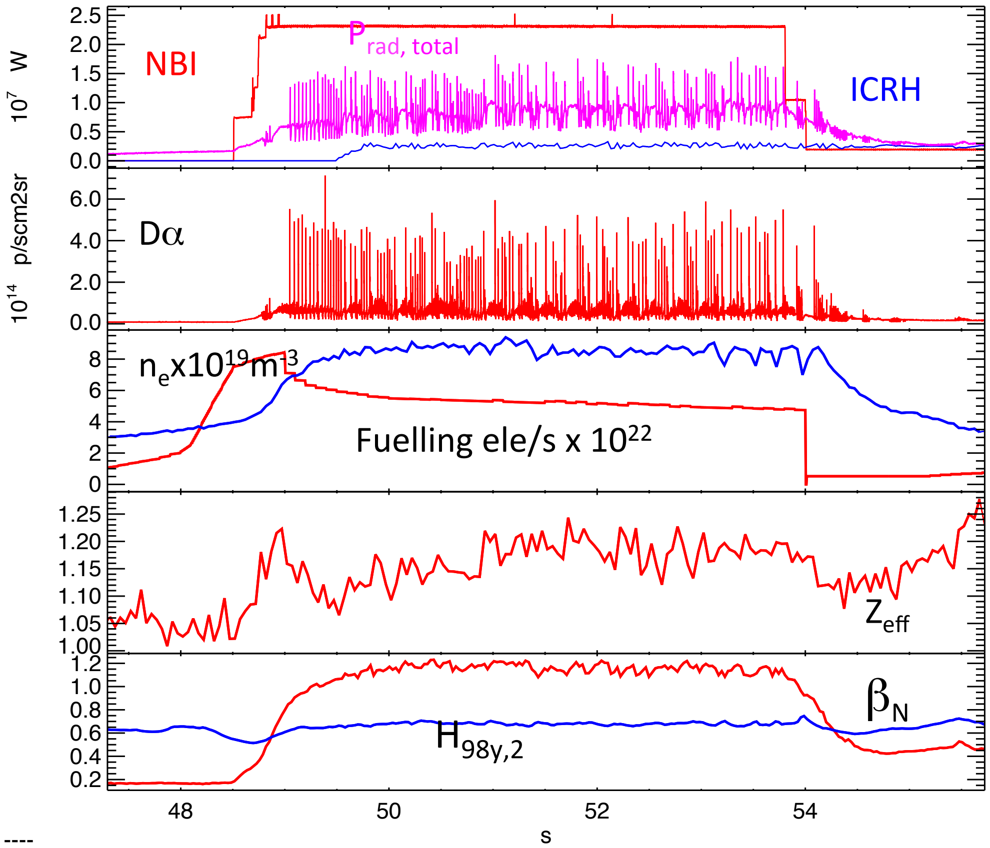
✓**Additional heating**

➔ **ELM frequency** ➔ **Impurities flushed out**

T. Puetterich

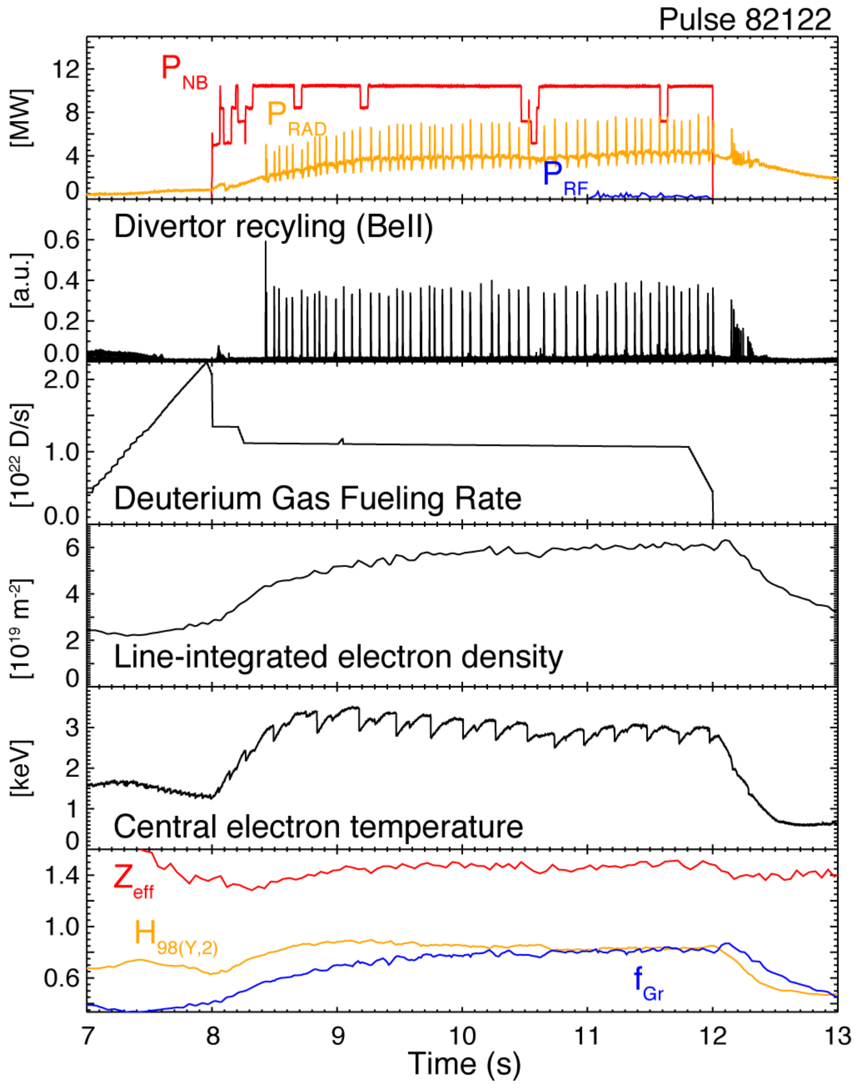
Controlling W accumulation - gas

- By increasing the gas fuelling is **possible to control the W accumulation** and increase plasma current safely
- Stationary H-mode established with the ILW up to **3.5 MA and 27 MW**



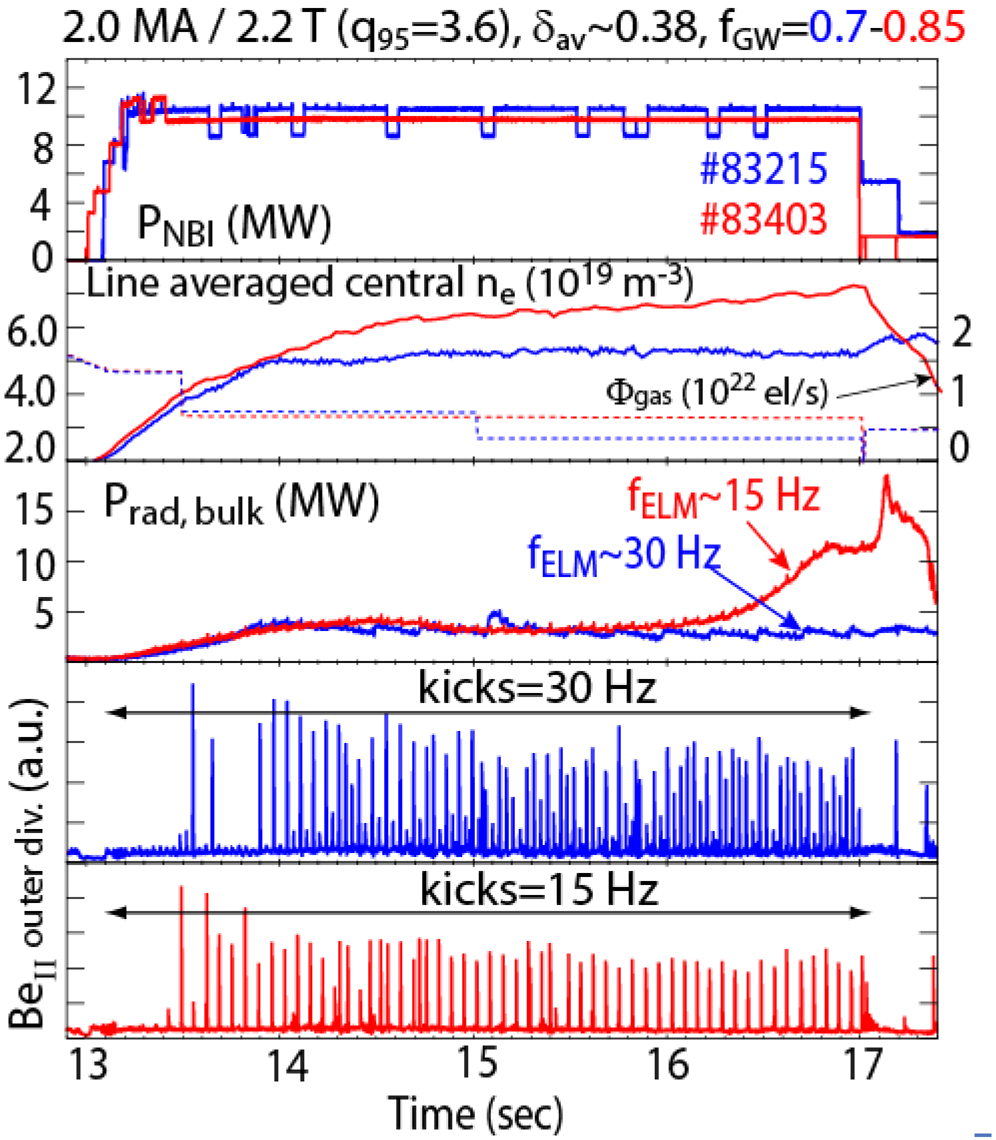
- $P_{IN}/P_{L\text{-}H}$~1.5
- Strike point sweeping implemented to reduced the temperature on the bulk tungsten tile (<1200°C)
- Confinement strongly affected by the gas only? H_{98}~0.7-0.8

Controlling W accumulation – power



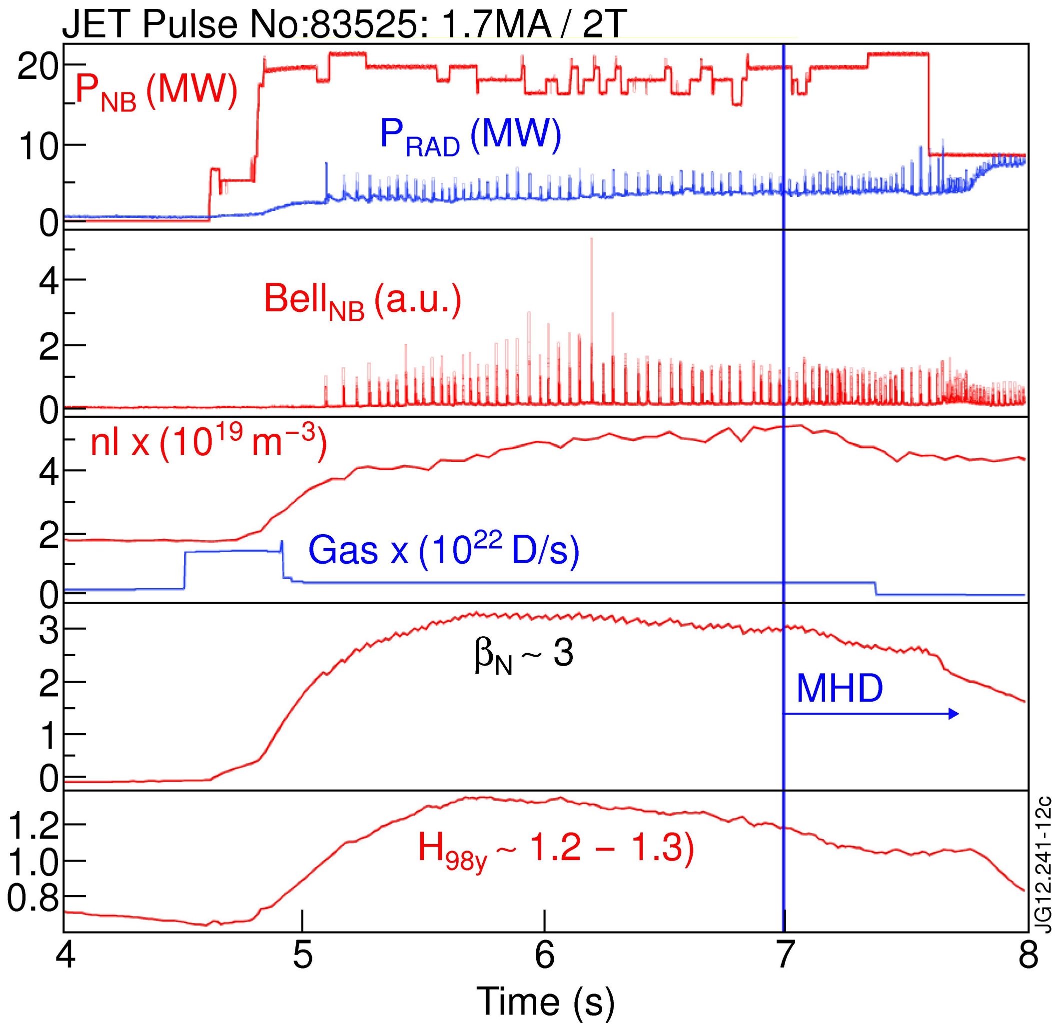
- Increasing power ➔ high-frequency Type-I ELMs can be achieved (rather than using high gas fuelling rate)
- confinement also improves
  - H_{98}~0.9
  - f_{Gr} ~ 0.9
  - Z_{eff} ~ 1.2 – 1.4

Controlling W accumulation – kicks



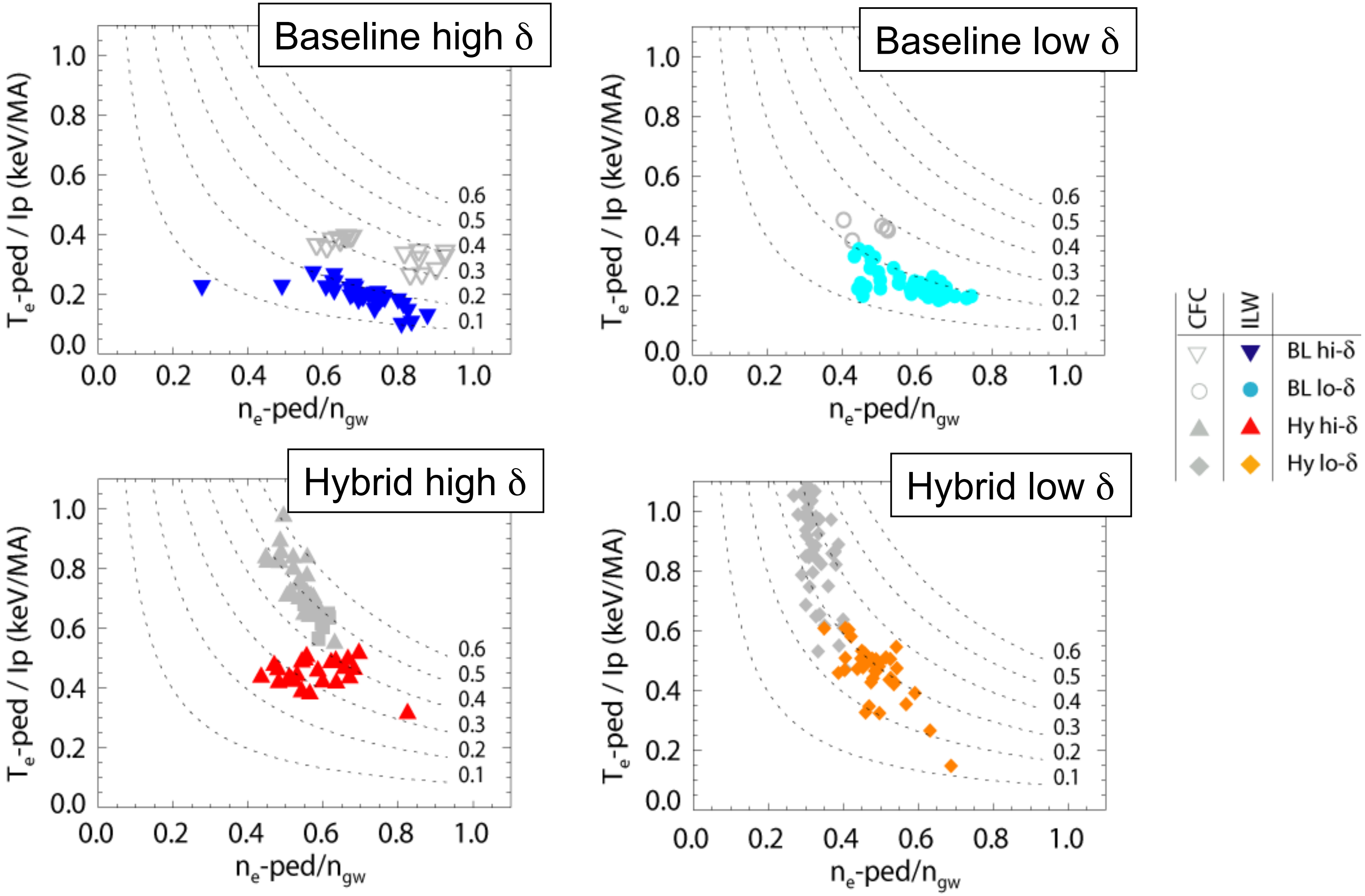
- Applying kicks → high-frequency Type-I ELMs can be achieved without affecting density
- No change in confinement

Hybrid H-mode



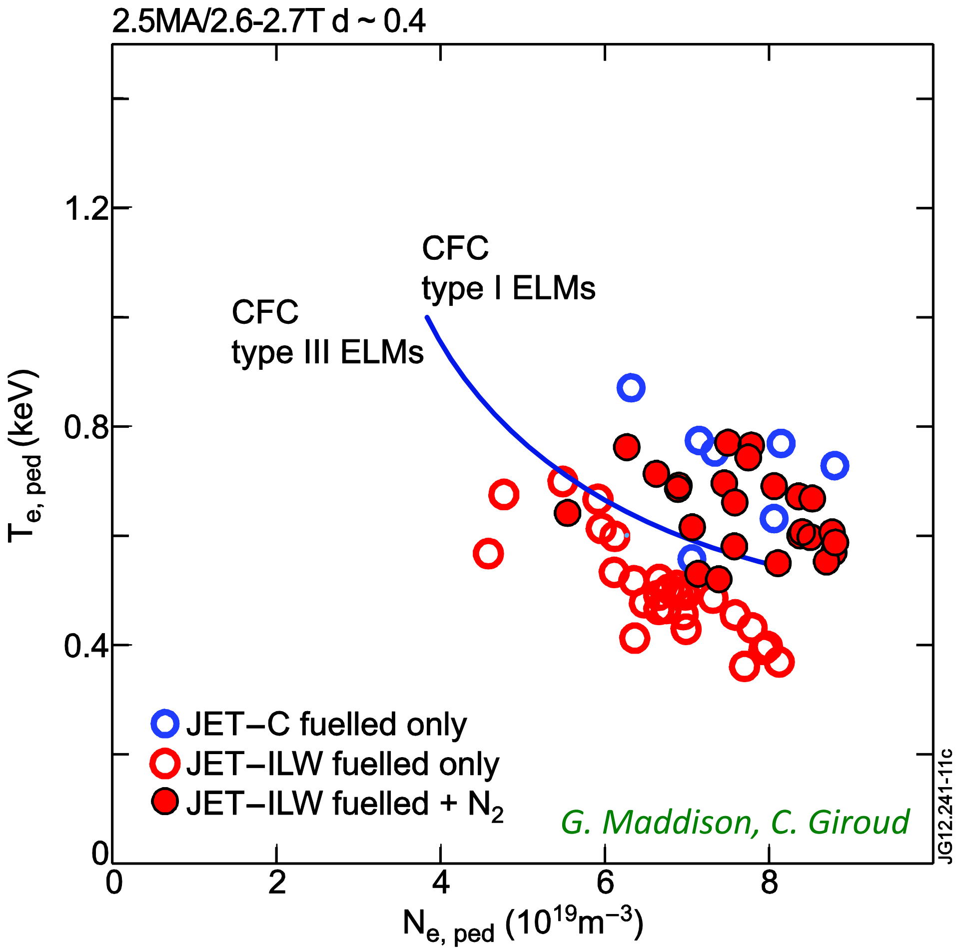
- Hybrid H-modes have been re-established with the ILW
- C-wall hybrid discharges in high d configurations have been transiently reproduced.
- **H_{98}~1.2-1.3 at β_N~3 achieved, similar to the C-wall**
- Duration of high performance phase typically limited by MHD

Pedestal confinement lower in ILW



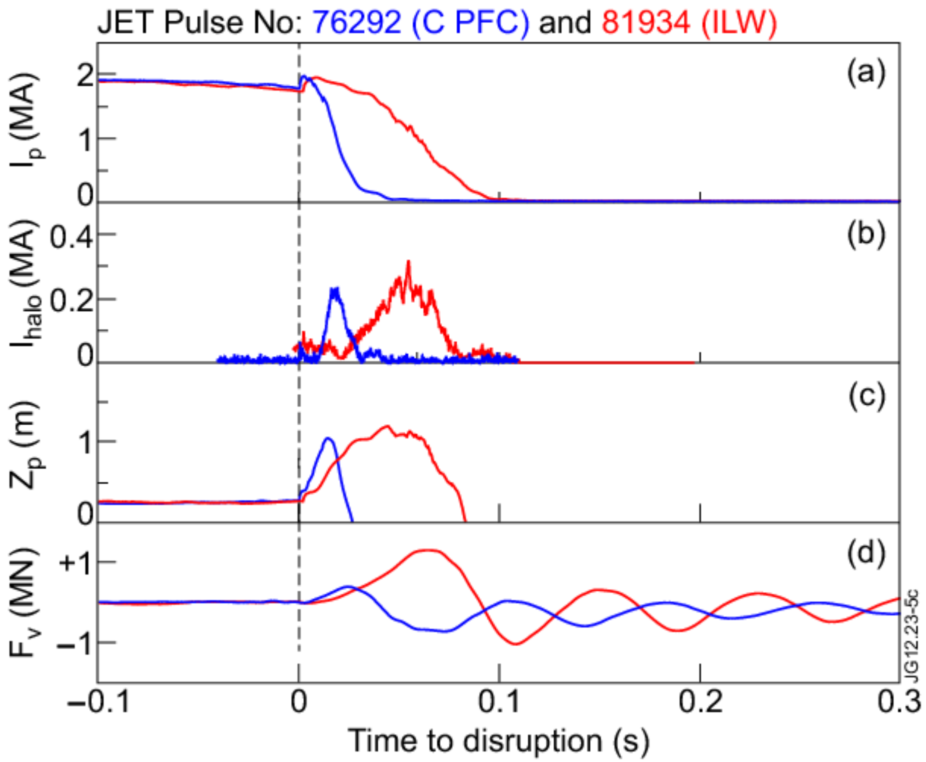
low delta less pedestal degradation than high delta?

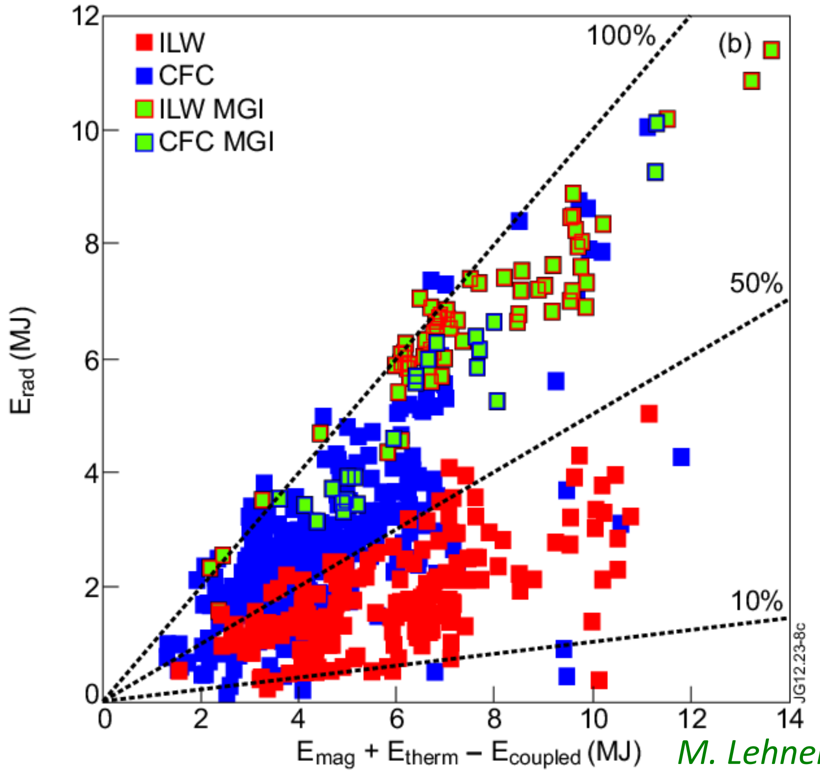
Seeded ELMy H-mode



- Reduced performance is due to reduced confinement in the edge transport barrier
- Adding nitrogen (required also for divertor power handling) improves the confinement!
- So far, only in high triangularity configurations

Disruptions



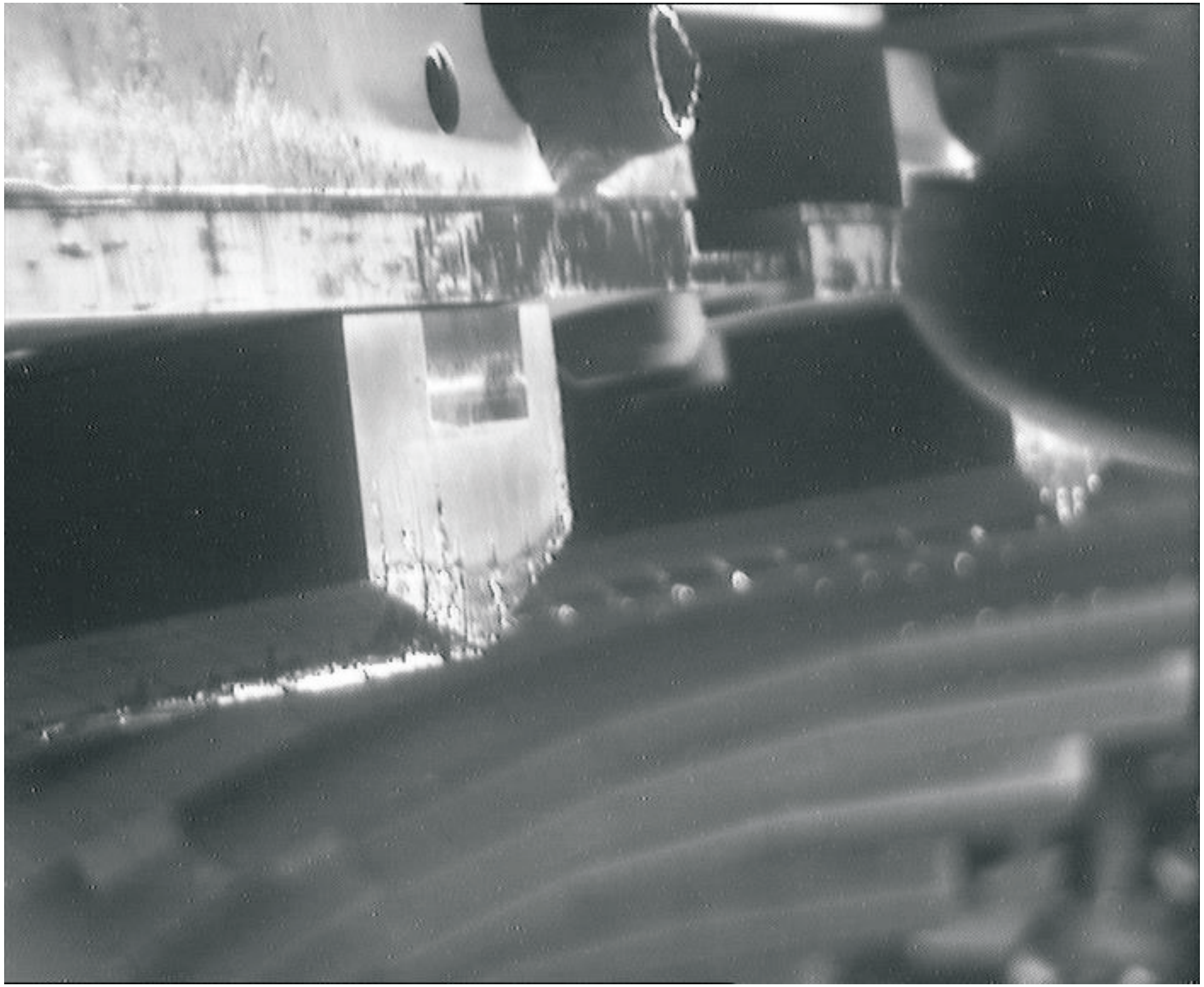


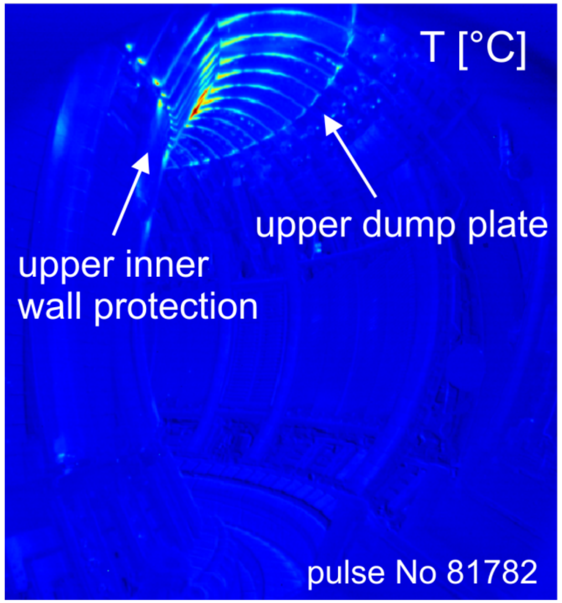
M. Lehnen

- With the ILW a much smaller fraction of the energy is radiated, which results in much longer current quenches.
- The longer current quench results in significant increases the swing or reaction force on the vessel.
- Low radiation fractions and high vessel reaction forces makes disruption mitigation a necessity at JET (for I_p>2.5MA).
- Massive gas injection (MGI) has been used as an **active** mitigation tool.

Melt damage after disruptions

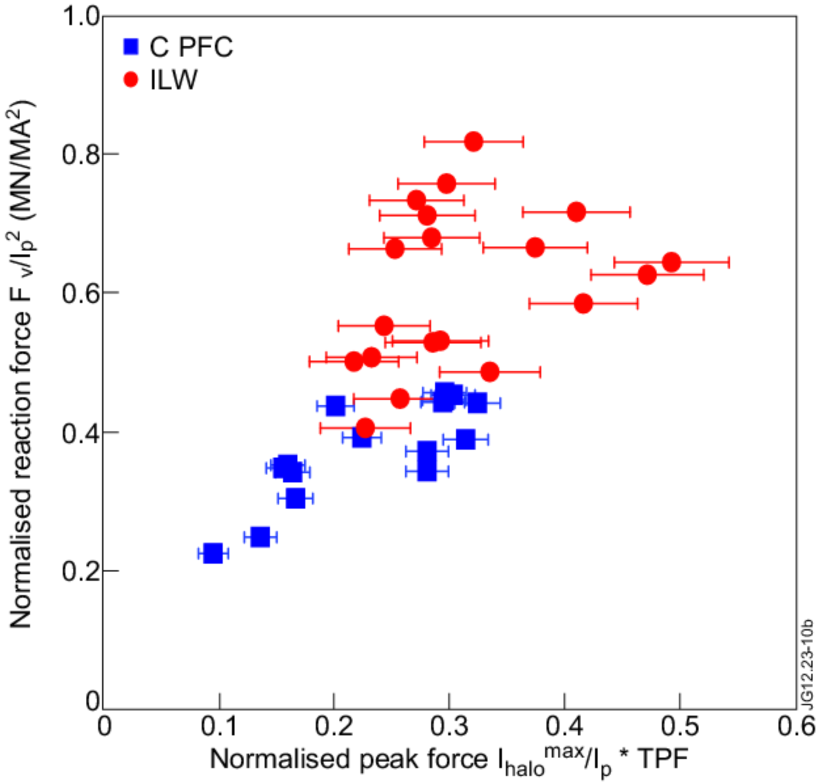
- Melting associated with VDEs at low I_p=1.5MA or E_{mag}=6MJ

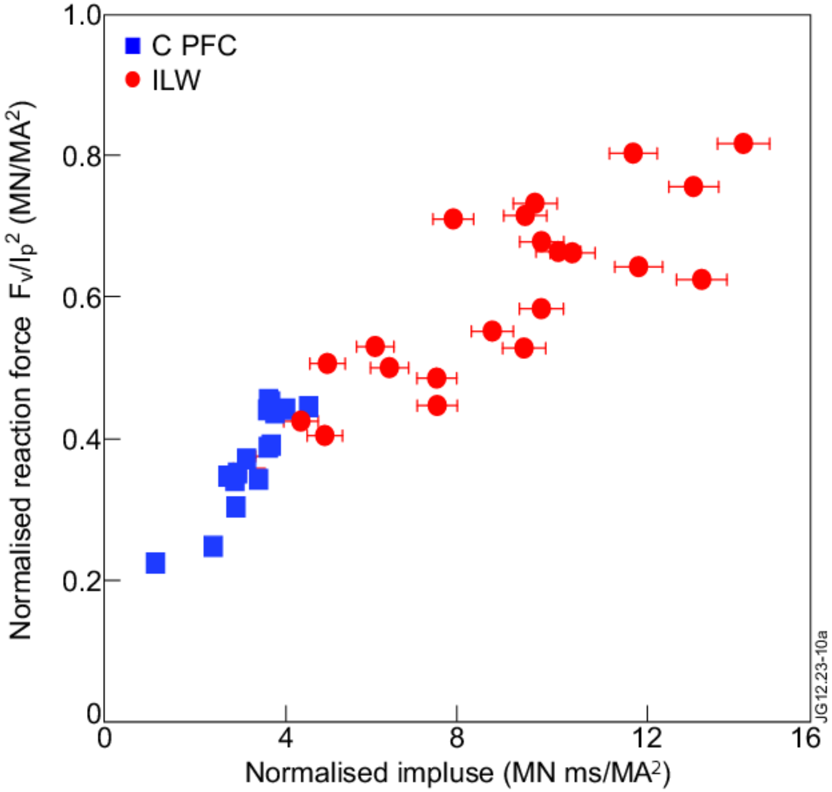




Disruption forces

- For the same halo current fractions → wide range of F_v
- But F_v scales with the time integrated halo force (impulse)
  - Longer current quench will result in a larger vessel reaction force*





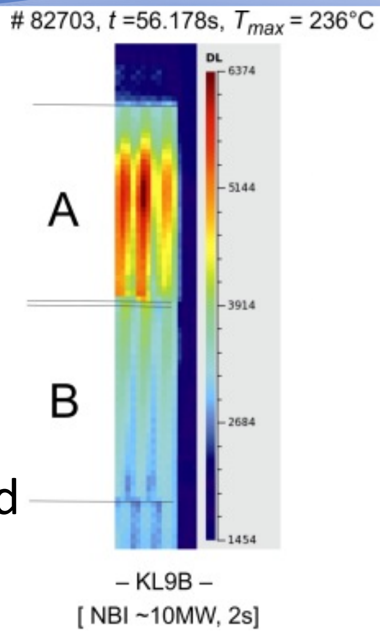
P de Vries, S Gerasimov

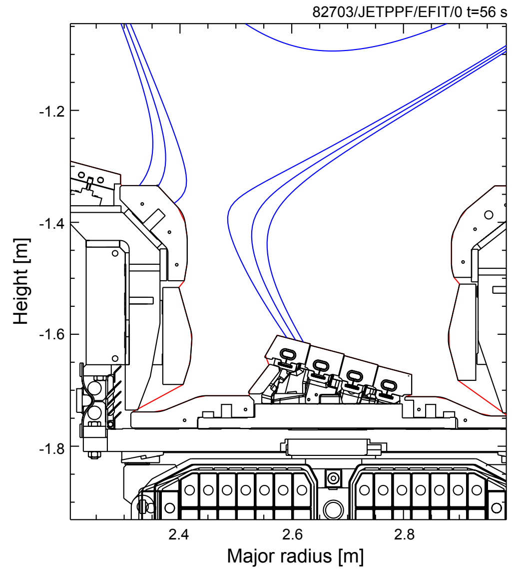
Top Priorities for 2013:

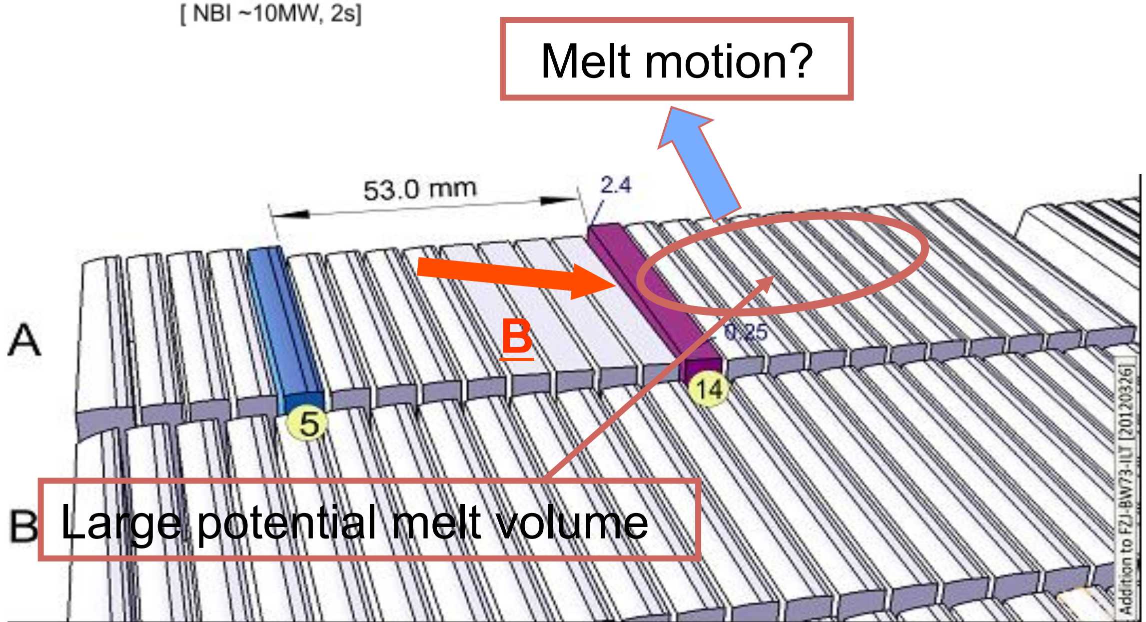
- Transient melt experiments takes highest priority for ITER
- Limitation of operational space by W and W control
- Runaway electron threshold and mitigation
- Experiments aimed at understanding ILW confinement behaviour
- Experiments related to fuel removal from co-deposits
- Request for a Hydrogen campaign in 2014

Special Lamellae Geometry

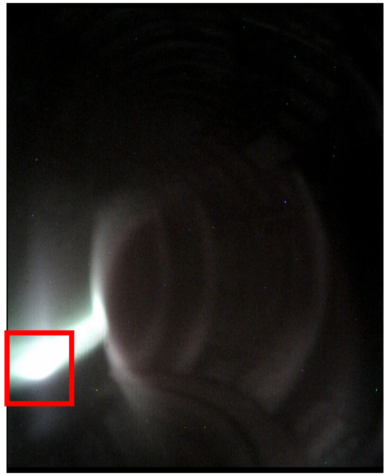
- Evaluate the behaviour of W melting by transients
- Evaluate the behaviour of re-solified shallow melt damage
- Study the possibility impact of transient melting on the main plasma

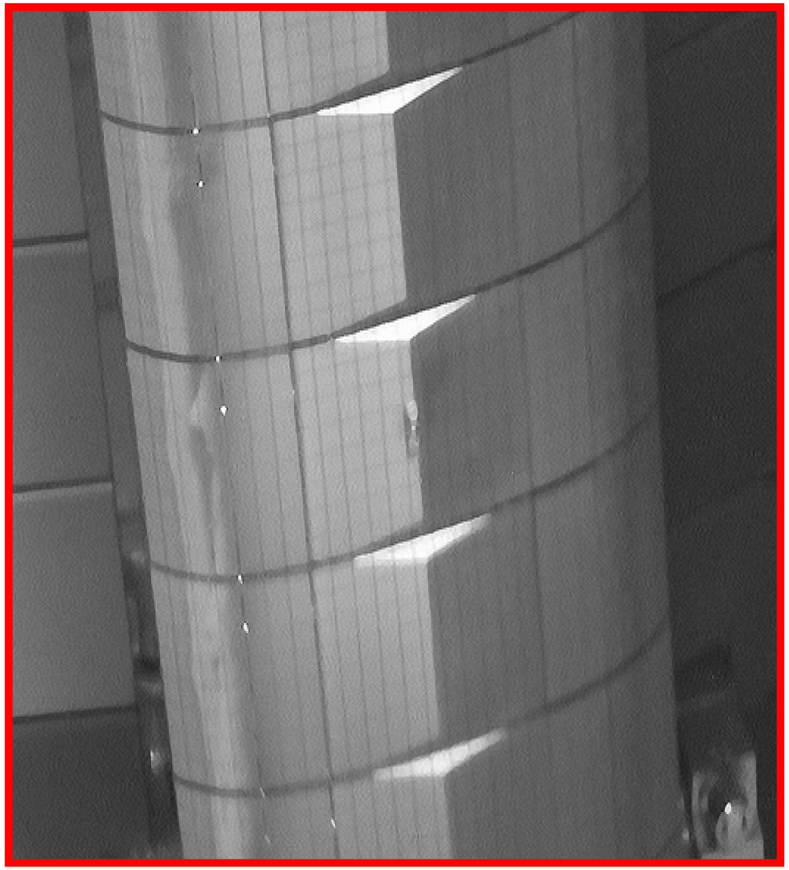






Runaway electrons

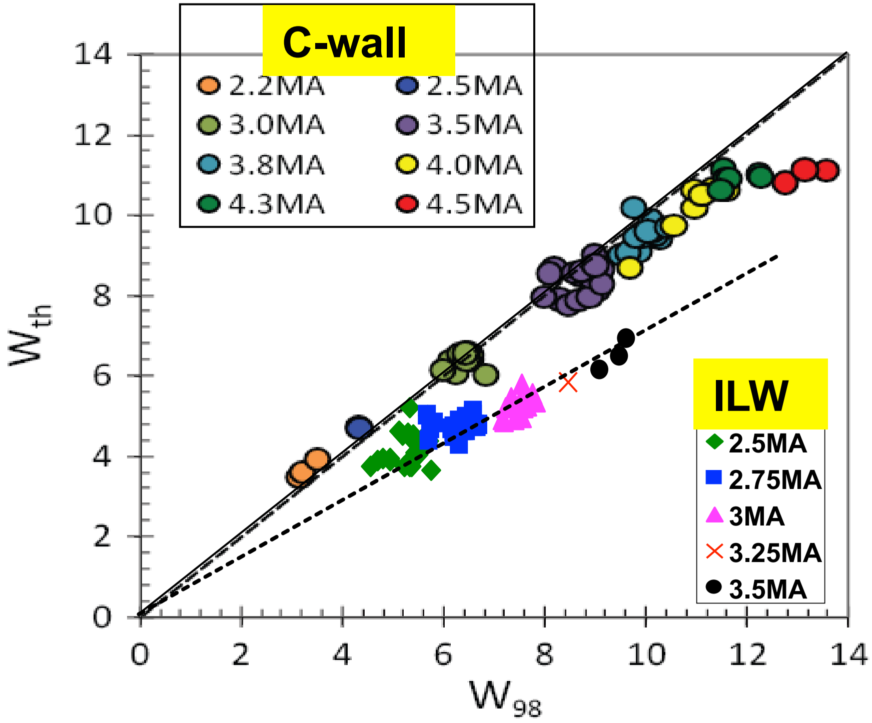




A slide-away event caused the first melt damage, within 100 plasma pulses from first plasma.

Control issue resolved + location away from normally used portion of limiter.

Baseline Scenario



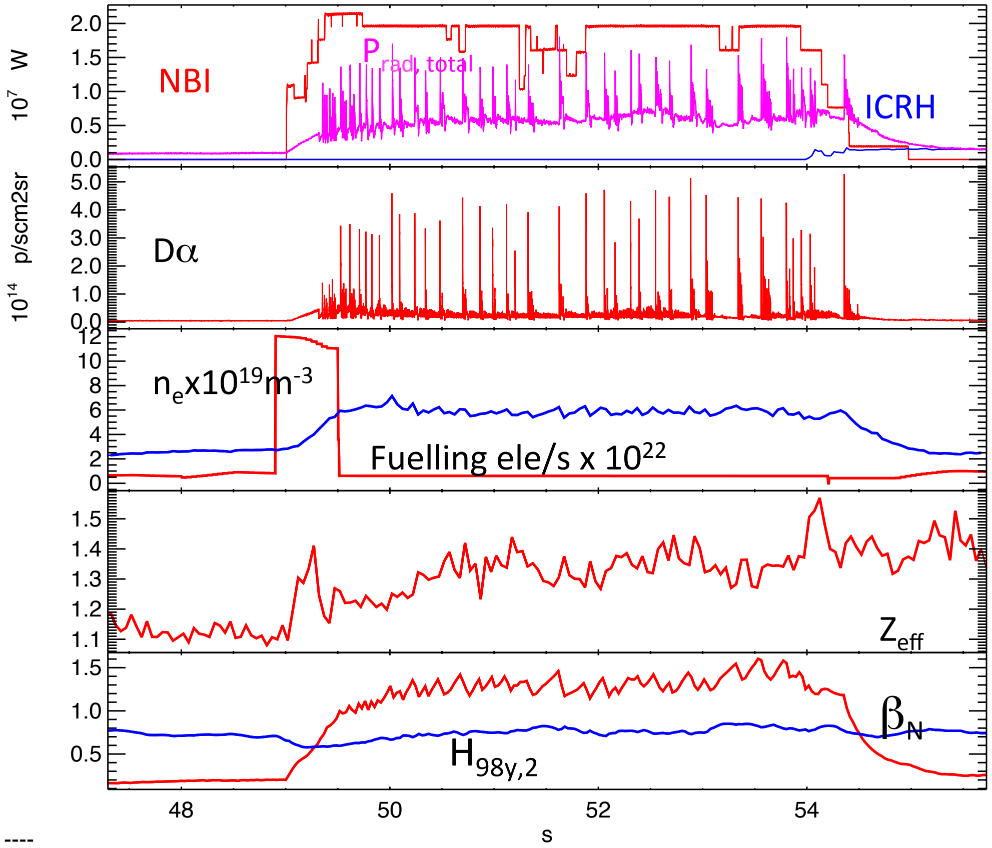
Confinement properties

- Dimensionless scaling of β_N, ν^*, ρ^* and β_p
- Confinement dependence with divertor geometry
- Confinement dependence with triangularity
- Control of W accumulation
- Operation on vertical target: reduces W source but confinement still low
- Compare hybrid with baseline scenario to understand confinement
- Pedestal stability

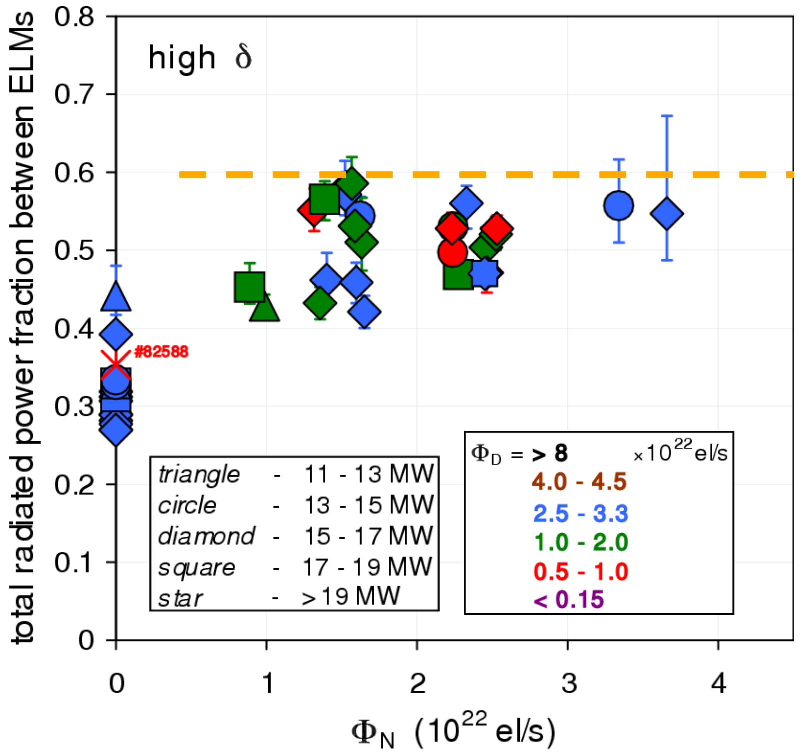
ITER scenario integration

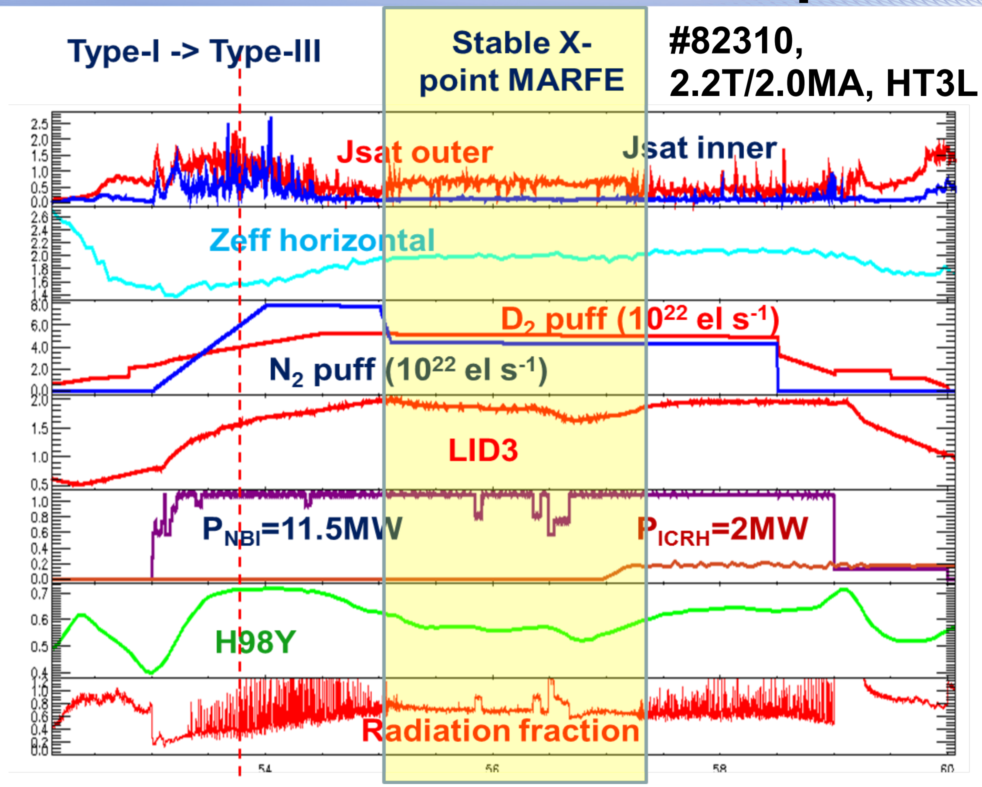
- Low r* and n*
- ITER ramp-up/ramp-down
- Access to H-1 close to P_{L-H}
- Termination :
    - exit from H-mode
    - flux consumption
- ELM mitigation techniques:
    - Kicks
    - Pellets
- Power load control with extrinsic impurities

Vertical target (tiles 3 and 7)



Detachment control using fuelling and extrinsic impurities

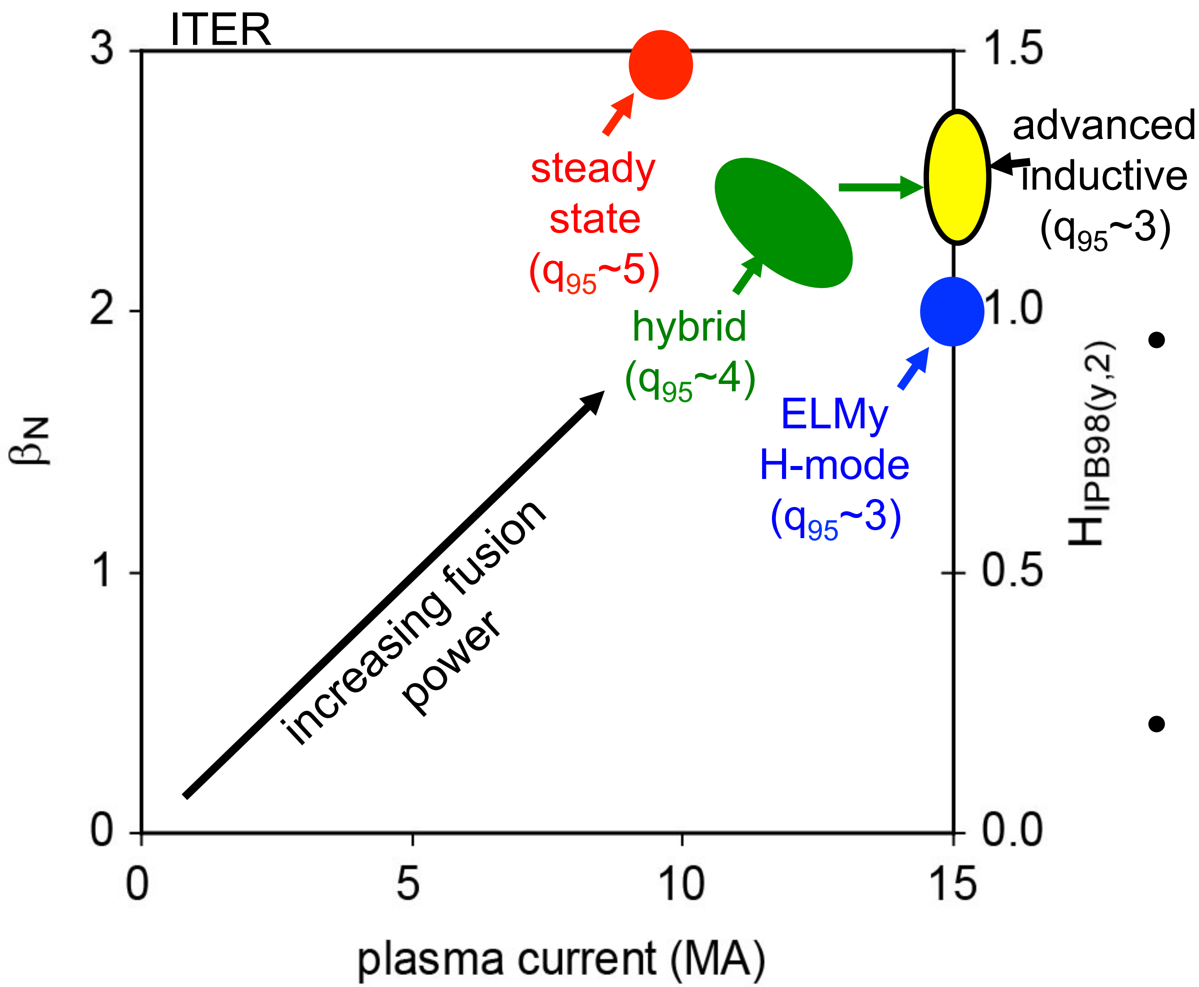




- **JET ILW:** D-fuelling+ **N**-seeding scans: $f_{RAD} \leq$ **0.6**
- **ITER:** f_{RAD} > 80%
- **DEMO:** f_{RAD}~ 97% is needed

- Type III ELMs established with N_2 seeding (f_{rad} > 50% up to 80%)
- The inner divertor is completely detached between type-III ELMs; the outer divertor is at least partially detached
- Confinement degradation for Type-III H-mode for f_{rad} > 65%.

Hybrid and Advanced Tokamak Scenario Development



- **Hybrid scenario extension low ρ* and ν* / optimisation**
  - Open the operating space further
  - Optimise performance
  - Wall compatibility
- **Confinement properties / Scenario overlap**
  - q-profile
  - Edge q
  - beta
- **Steady state scenario**

Assess need or not for GDC during ILW pre-conditioning based on bakeout at 200^{o}C

- ITER design is challenging → GDC nodes must be placed in port plugs
- evidence from first ILW campaign that the need for further deuterium GDC following restart of operations is much reduced in comparison with the all-C device

Planned experiment

Option 5	Plasma 130C water on LN2 on Reheat to 200C	GDC at 200C 24hr water on LN2 on	GDC at 200C 24hr water on LN2 on	GDC at 200C 17hr Cool to 130C water on LN2 on	Pump down Plasma 130C Reheat to 200C water on LN2 on	GDC at 200C 48hr water on LN2 on	Pump down Plasma at 200C O/N LHe+Be evap	**Plasma** LHe+Be	Restart	5	0

Will need one week of operation campaign → not yet approved