DIFFER

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INTEGRATED TOKAMAK MODELLING

Current ramp up in ITER: effects of impurity density

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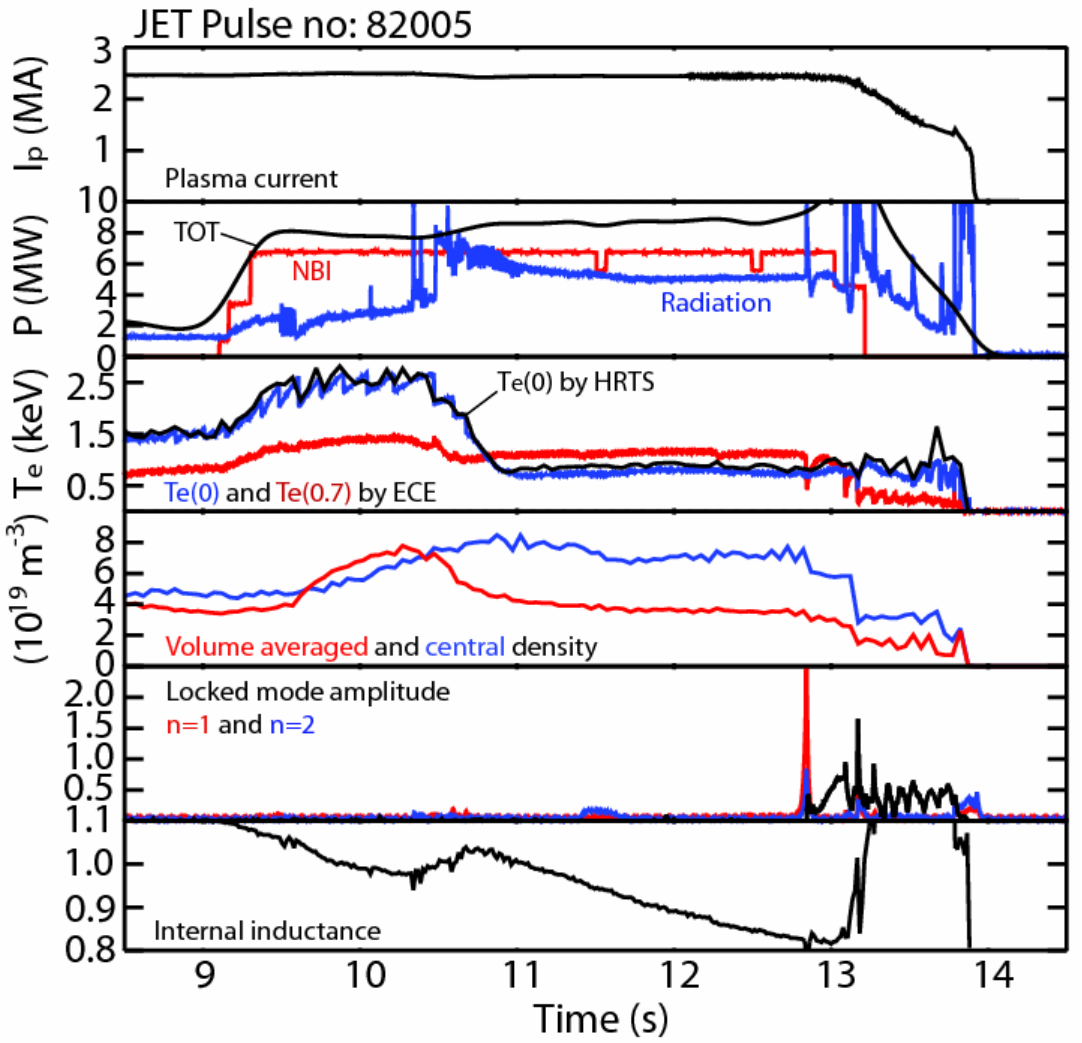
Outline: *- What radiation can we expect by given impurity concentration*

- Effect of adding small concentration of W in ohmic ITER ramp-up

- Effect of applying ECRH from early in RU

DIFFER is part of FOM and NWO

Motivation: with ILW in JET some discharges develop strong core radiation



Example pulse 82005:

P_{rad} (suddenly) increases (10.5s)

(P_{rad} remains below P_{tot})

Observations:

- T_e profile hollow; Sawteeth disappear
- Strong density peaking
- Although n_e and T_e stabilize, l_i and q keep changing
- n=1,n=2 MHD activity → mode locking →disruption

Question: what W concentration can the plasma "survive" (i.e. without strongly perturbing Te, q, li, etc.)

Here we concentrate on the current ramp-up phase (which is most vulnerable)

What radiation to expect: Radiation Model for W

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a. Radiation data from D.Post. et al,

At. Data Nucl. Data Tables 20 (1977) 397

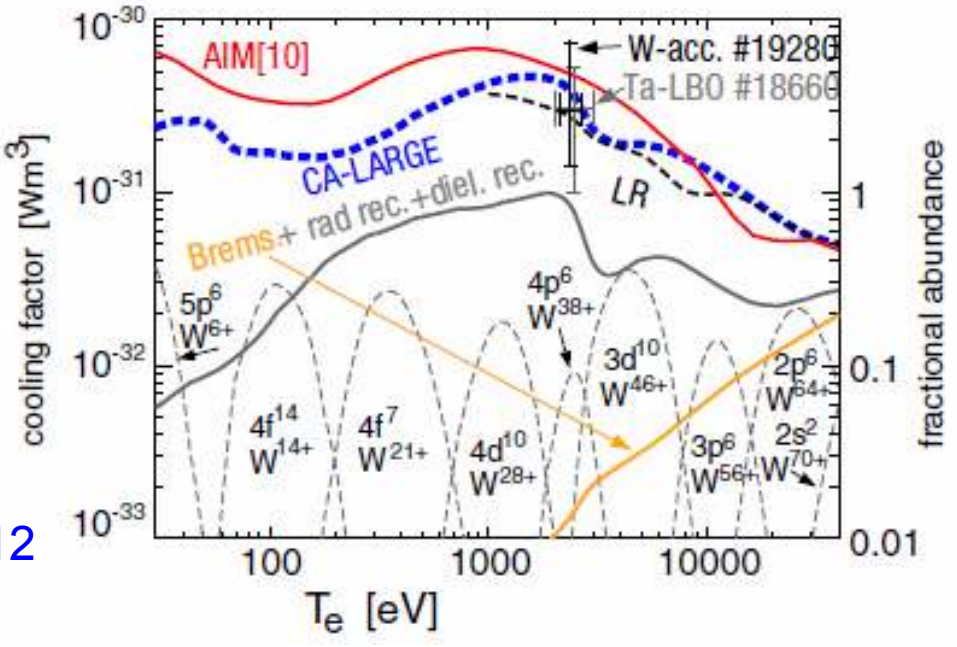
Uses "Average Ion Model" (corona eq.)

This is used in CRONOS

b. More sophisticated, using more detailed atomic physics:

Th.Pütterich et al, Nuc.Fus. 50 (2010) 025012

"Calculation and experimental test of the cooling factor of tungsten"

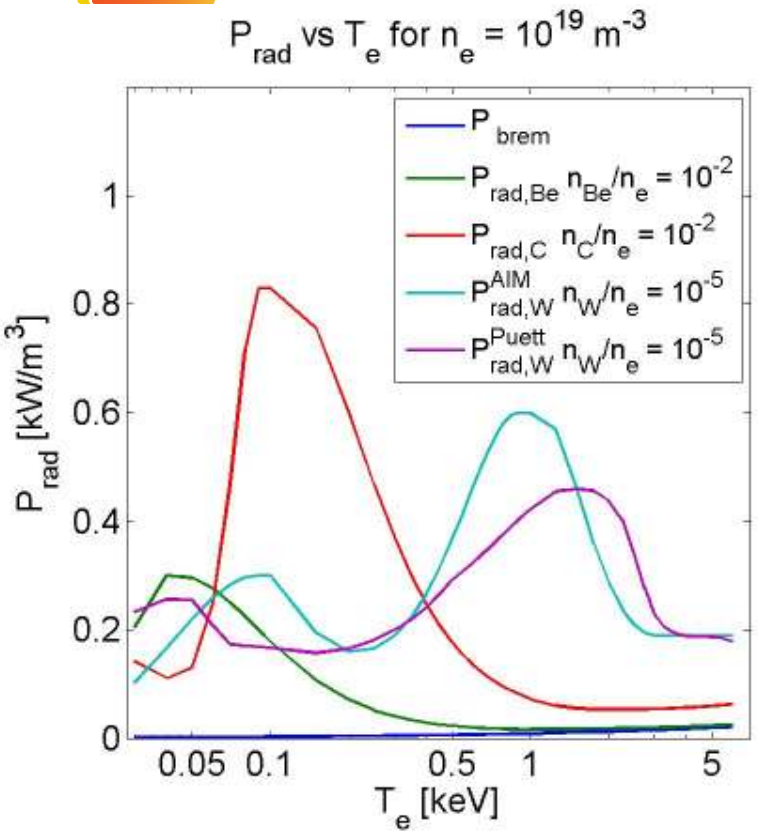


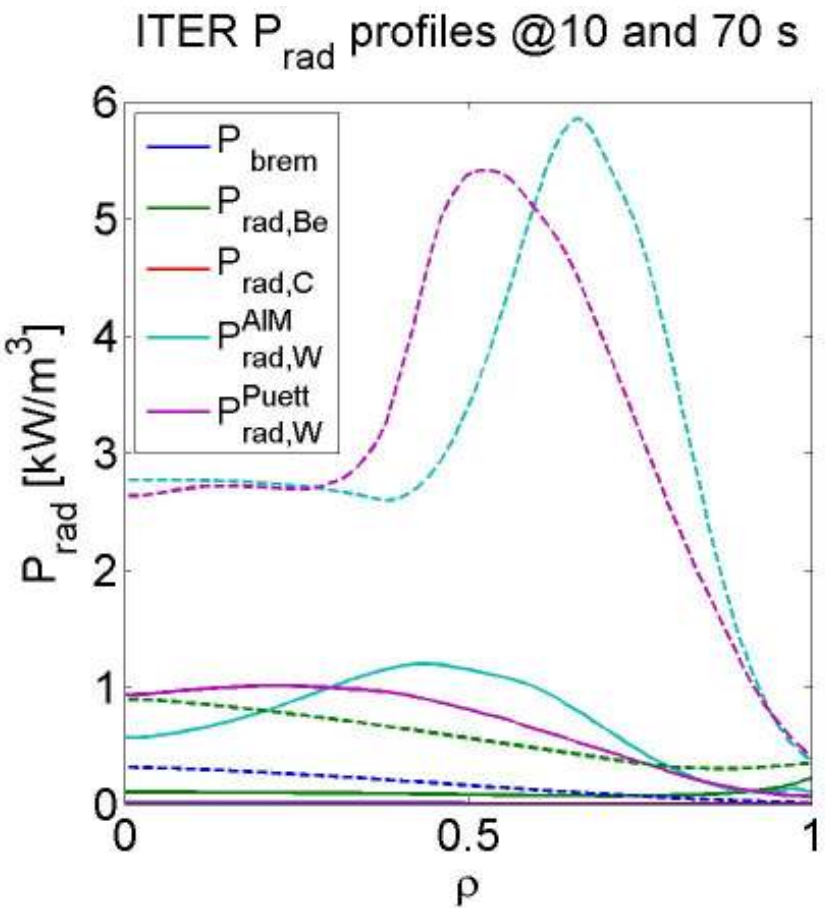
New data

- radiation peak shifted to slightly higher temperature (from 1 keV to ~1.5 keV)
- radiation peak bit lower and wider

(note logarithmic scale on both x and y axis!)

What radiation to expect from C, Be and W?





Radiation as function of T_e

Note W conc. 10^3 times lower than C, Be

For W both AIM and Pütterich

W radiation peak at 1 / 1.5 keV (AIM / Pütt)

Example from ohmic ITER ramp-up at modest $n_e = 0.25 * n_{GW}$ and $n_W / n_e = 10^{-5}$

full / dashed lines : @ 10 / 70 s

Predictive modelling ITER ramp-up

Notes general:

- Use n_e as given by ITER team: $n_e = 0.25 * n_{e,GW}$
- Flat Z_{eff} assumed, as given by ITER team (i.e. Z_{eff} decreasing with increasing n_e);
- Ohmic RU
- Moderate ramp-up up to 12 MA @ 80s

Notes on simulations:

- The CRONOS suite of codes is used
- Start from 1.5 s when $I_p = 0.5$ MA
- Use simple AIM model for W radiation

  however, comparison with Pütterich model will be shown for one case]
- Bohm-gyro model used, original L-mode version

  Note: first-principle model like GLF23 does not work well in L-mode ramp-up phase

ITER Predictive modelling
time traces

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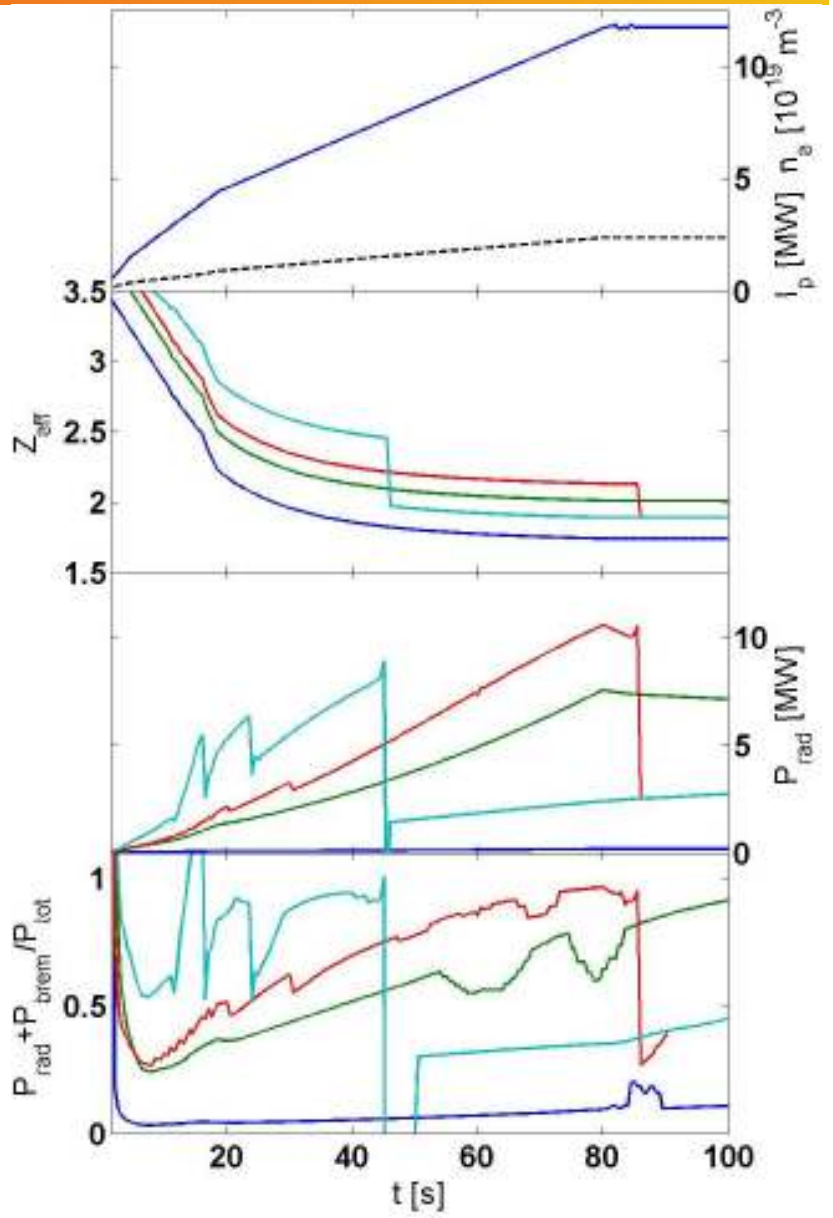
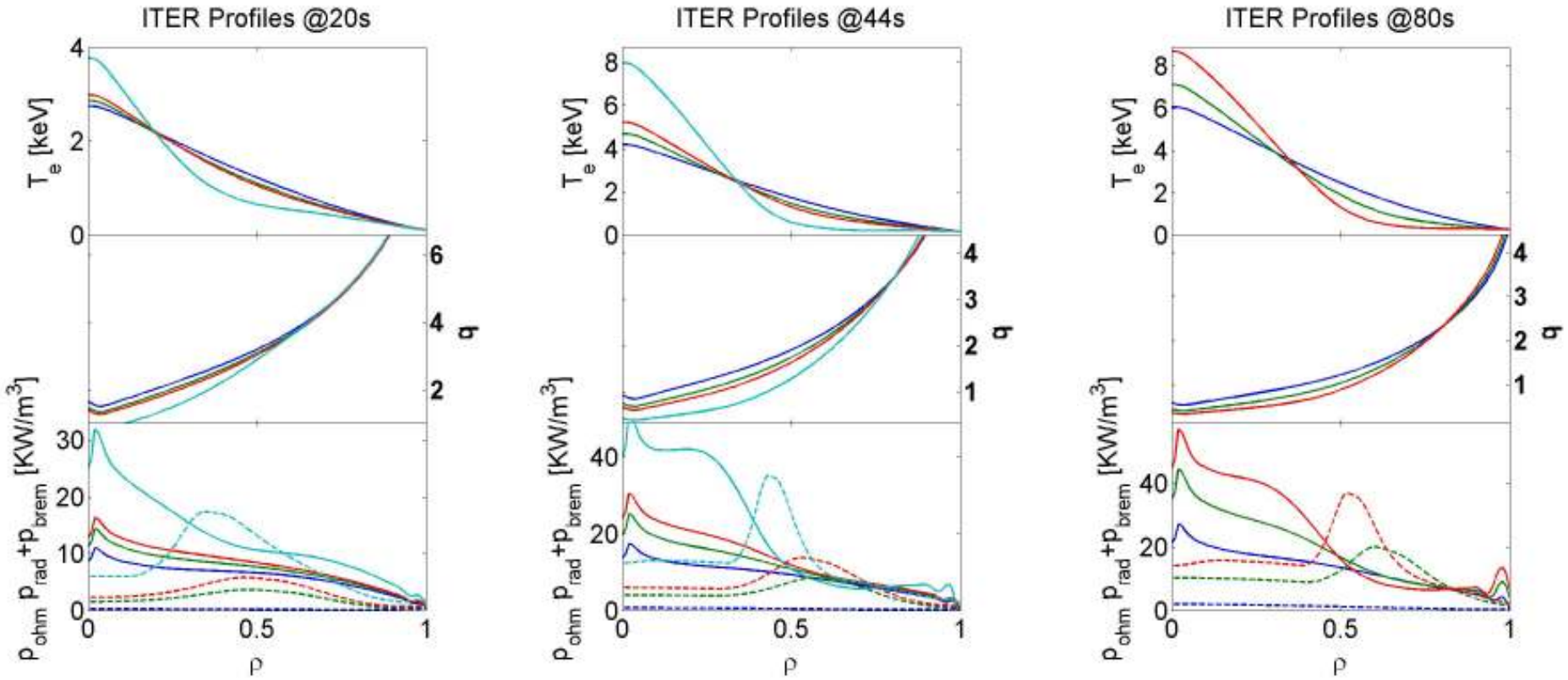
Blue: only impurity is Be4+,
Green: same Be4+, added W, nW/ne = 5 10^{-5}
Red: same Be4+, added W , nW/ne = 10^{-4}
Cyan: same Be4+, added W , nW/ne = 2 10^{-4}

Notes:

- Very significant radiation when $n_W / n_e >= 5\ 10^{-5}$
- With $n_W / n_e >= 10^{-4}$ the radiation losses lead to a "numerical disruption" (after 85 / 45 s), caused by T_e dropping to 0 near edge (next slide)



ITER Predictive modelling
profiles



Same colour coding as previous plots

Notes:

- n_W/n_e = 2 10^{-4} W: profiles already deviate @20 s; @44 s large T_e ~ 0 region for ρ >0.6
- n_W/n_e = 1 10^{-4} : same happens at end of ramp-up

ITER Predictive modelling
Closer look

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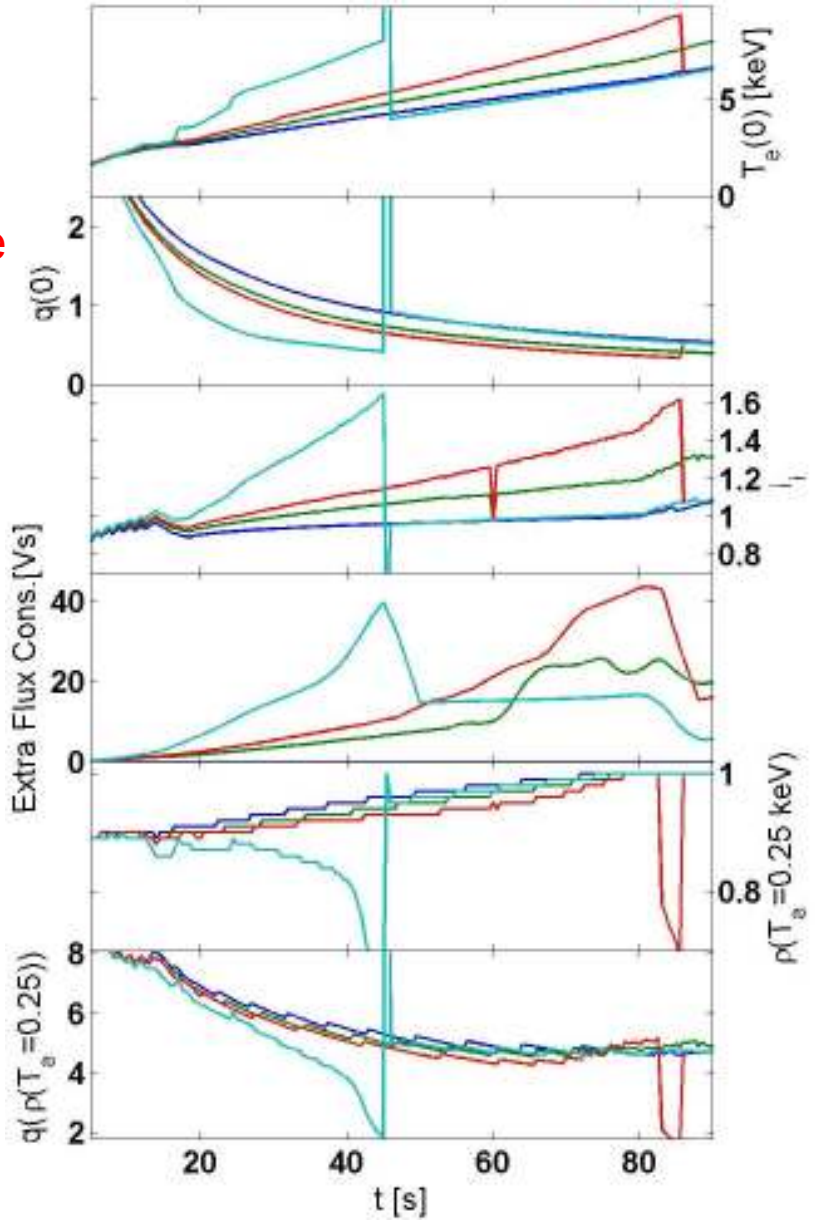
Closer look – same colour coding as before

Many problems arise due to very peaked T_e profile & strong radiation loss in outer area:

- very low central q *(2nd panel)*
- l_i becomes far too high *(3rd panel)*
- lot of extra flux consumption *(4th panel)*
- shrinking of effective plasma volume *(5th panel)*

  → q=2 at effective plasma edge *(6th panel)*

With timely application or ECRH all these problems can be avoided (at least up to the W concentrations considered here) → next sheet



ITER Predictive modelling
mitigation with ECRH

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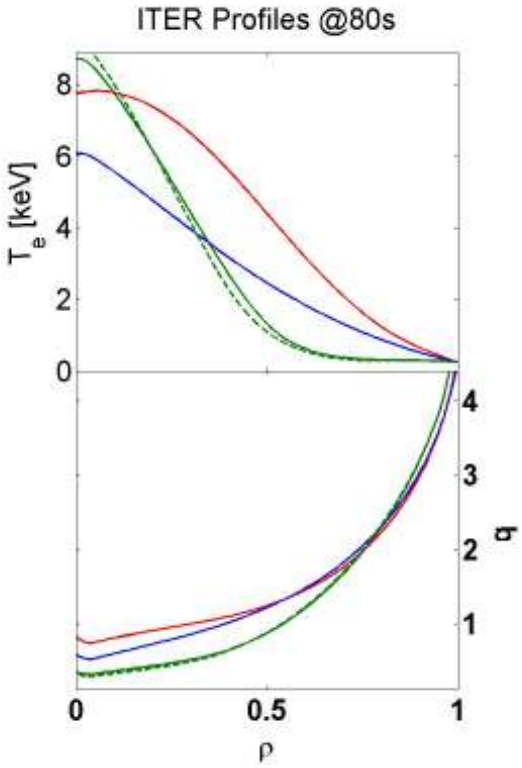
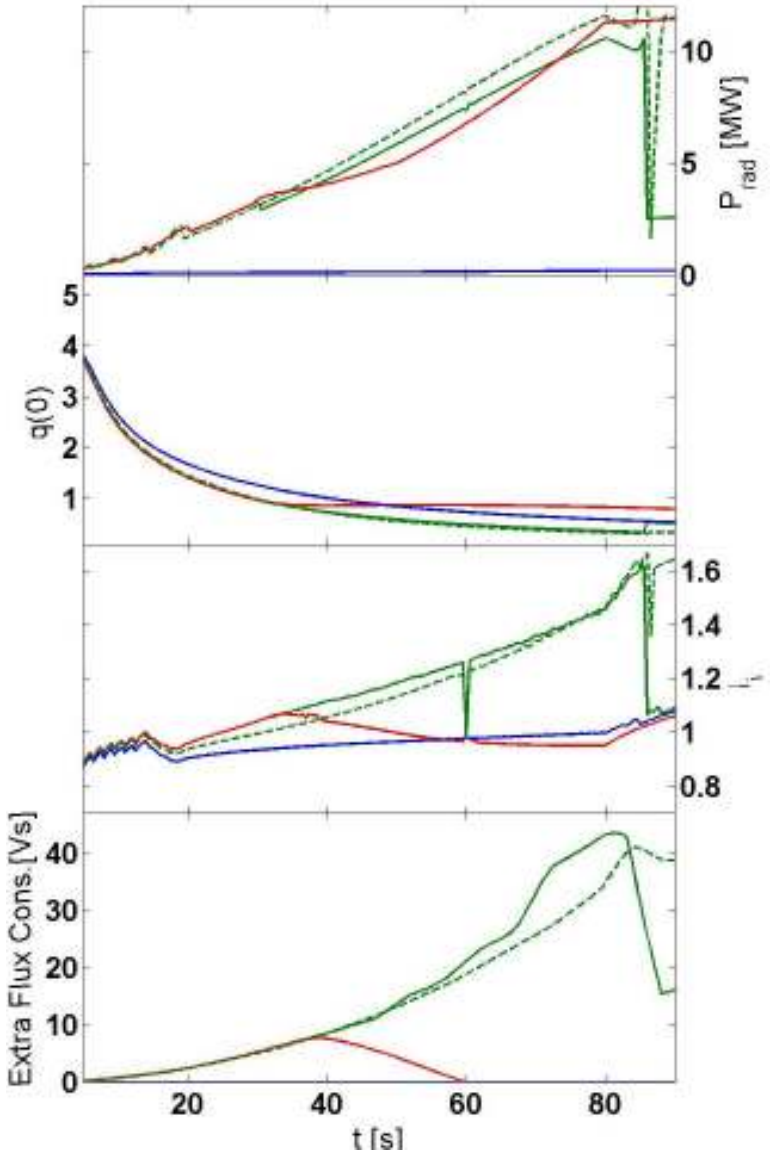
Analyze effect of ECRH:
Blue: ohmic, only impurity is Be4+,
Green: same Be4+, added W, nW/ne = 10^{-4}
Green dashed: same, *improved radiation model*
Red: same, *with added off-axis ECRH*
(at ρ = 0.4 and 0.6),
ramped to 20 MW between 30 and 50 s

Effects of ECRH:

- l_i restored to safe range
- extra flux consumption more than compensated
- T_e profile back to normal
- central q close to 1

Improved radiation model (Pütterich): *no significant effect on results*





Conclusions & Outlook

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Conclusions:

- For an ohmic ramp-up at moderate density, assuming flat Z_{eff} and uniform n_W / n_e the critical W concentration is n_W / n_e is just below10^{-4}
- Above this W concentration, the T_e profile develops a 0 region outside ρ ~0.7, thus inducing strong peaking of current density, and strong problems regarding l_i, flux consumption and MHD
- With 20 MW of (off-axis) ECRH applied from early in the RU, the critical W concentration is much higher
- These results are independent of the W radiation model used

Further work:

- What W concentration acceptable in ITER with ECRH from early in RU?
- Analysis of JET ILW ramp-ups, cases with strong W radiation:
  - W profile (is n_W more peaked than n_e ?)
  - Te and q profile evolution in such cases