Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement (incl. comparison of IWL cases with C wall and baseline scenario)

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TFE1/E2 meeting 18.12.12

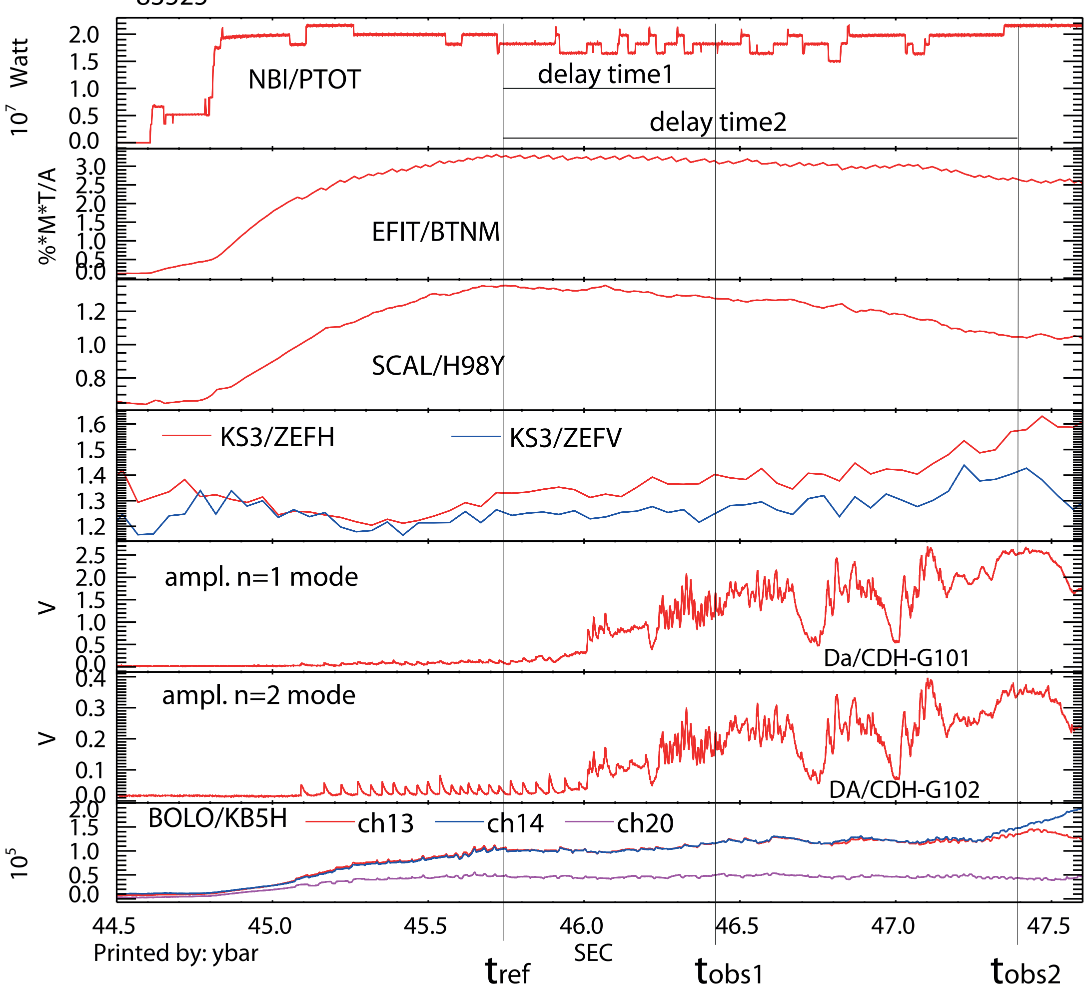
Outline:

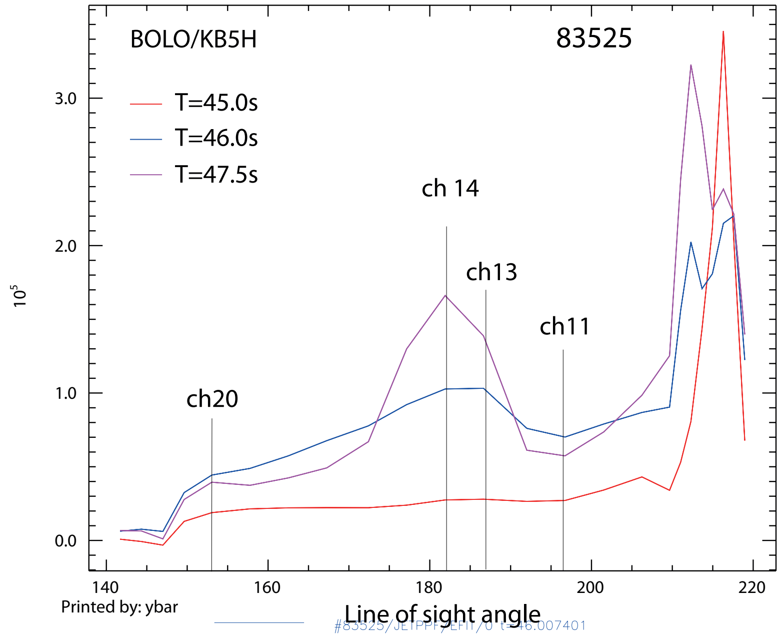
- Database definitions and parameters
- Correlation and analysis
- Conclusions

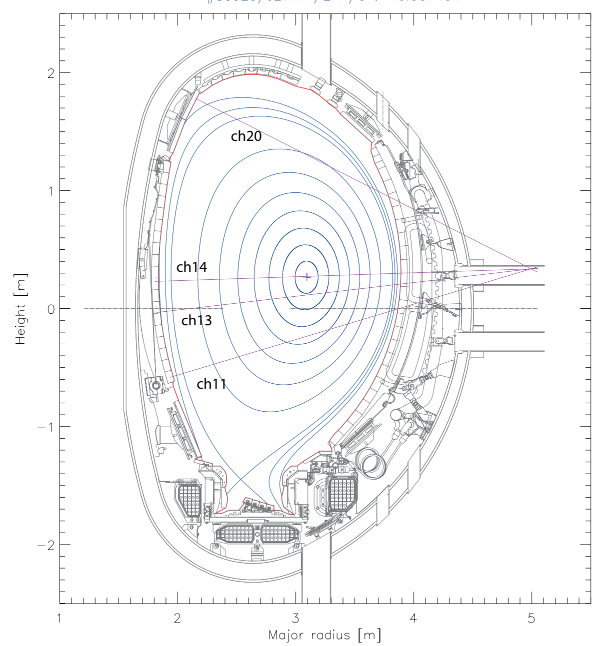
Database parameter definitions:

Max(betN)-reference time - Tref,

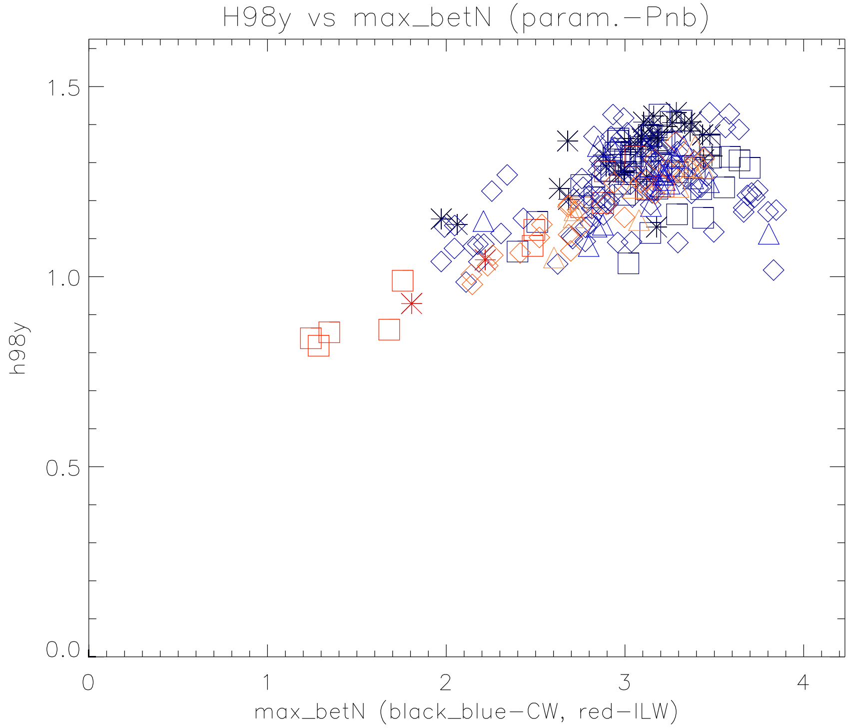
Observation time - Tobs= Tref+delay time

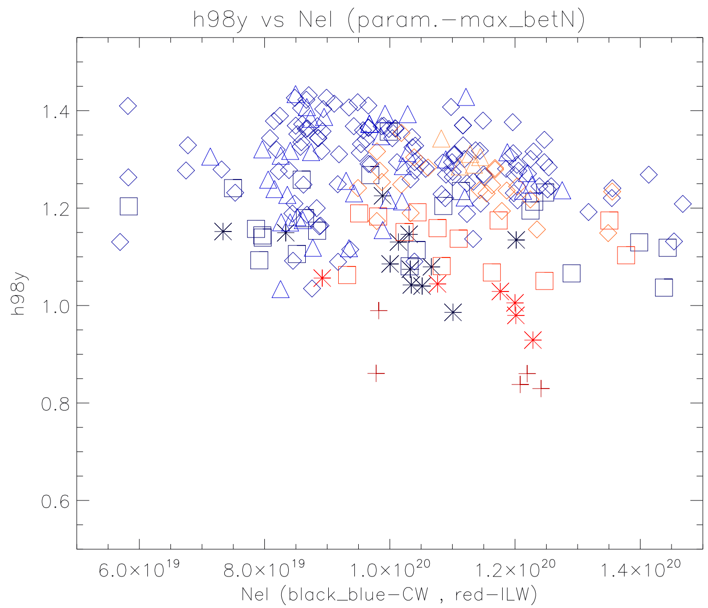


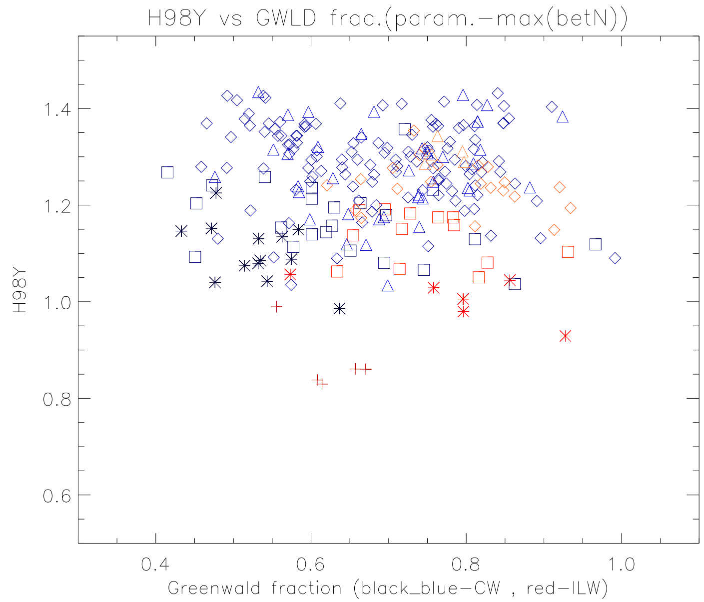




Comparison of the H factor in hybrid pulses with ILW and C-wall at t=tref (at max(betN))



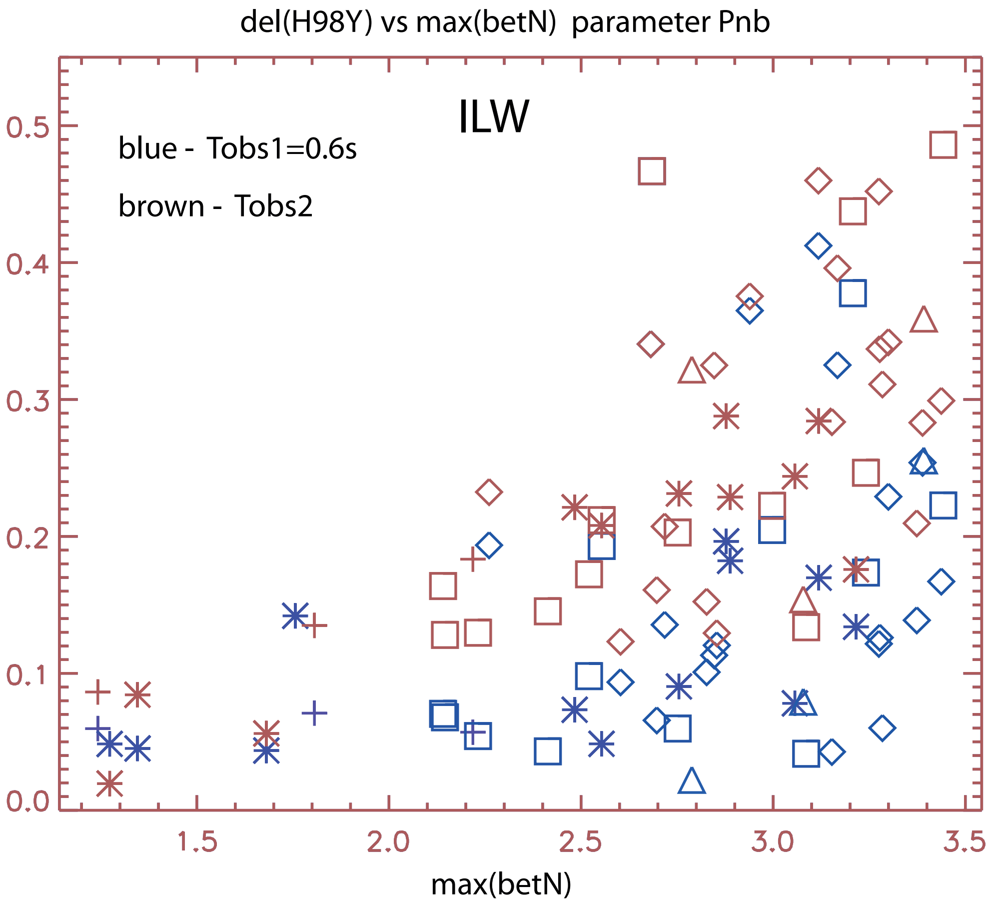


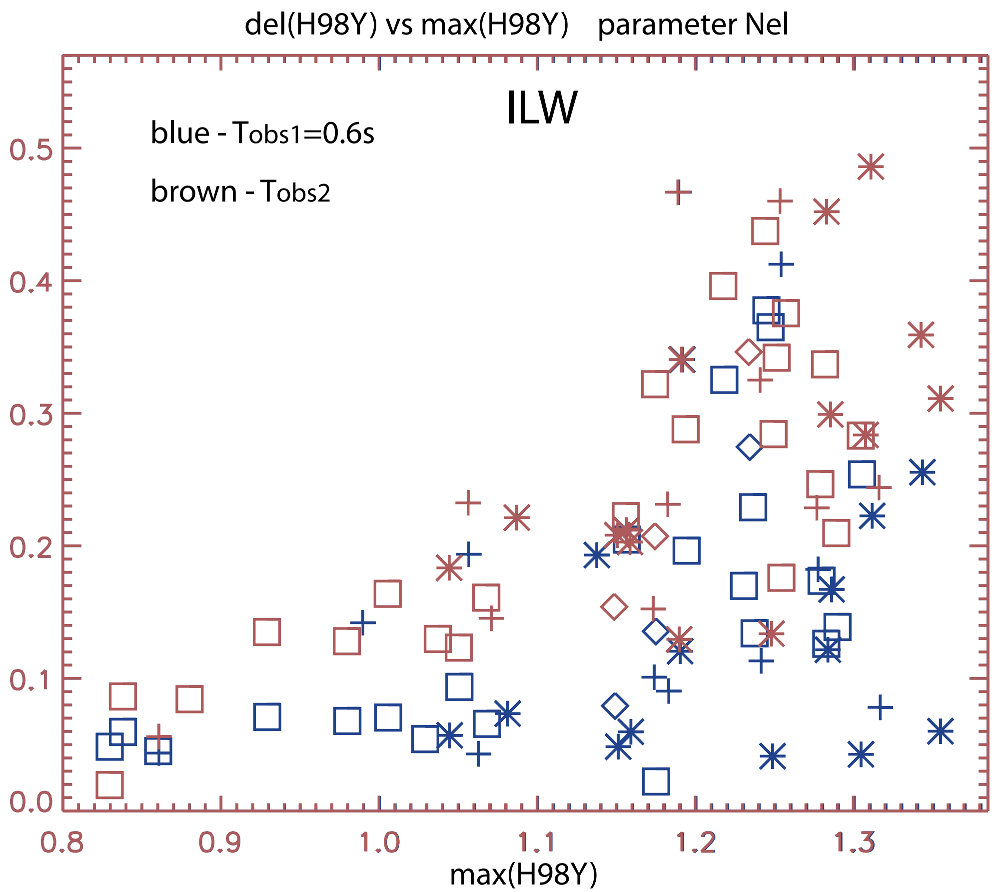


Greater part of hybrid pulses are included.
Excluded pulses with “micro” disruptions (C-wall) and large radiation events at the periphery (ILW)

Confinement degradation in hybrid pulses with ILW

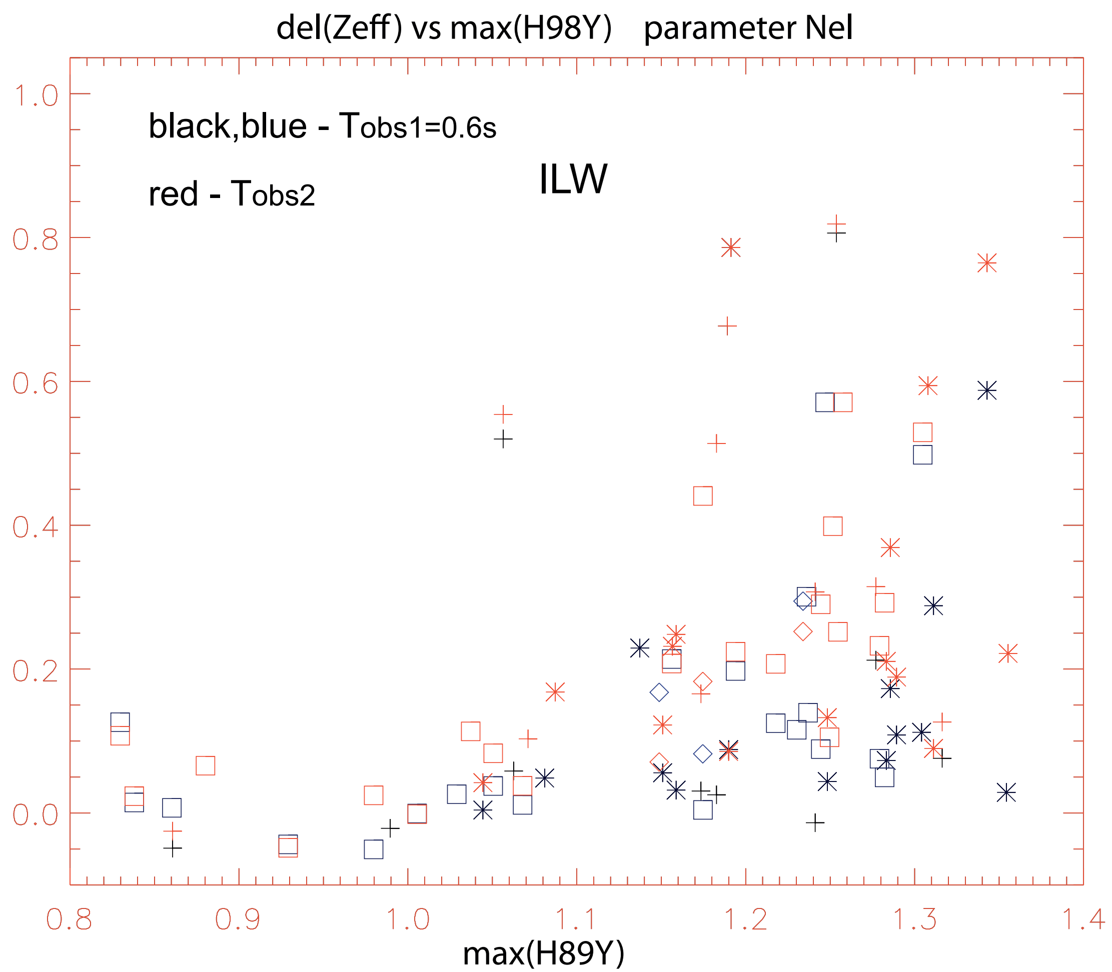
del(H98Y)=max(H98Y)-H98Y(tobs)





Zeff increase in hybrid plasmas with ILW

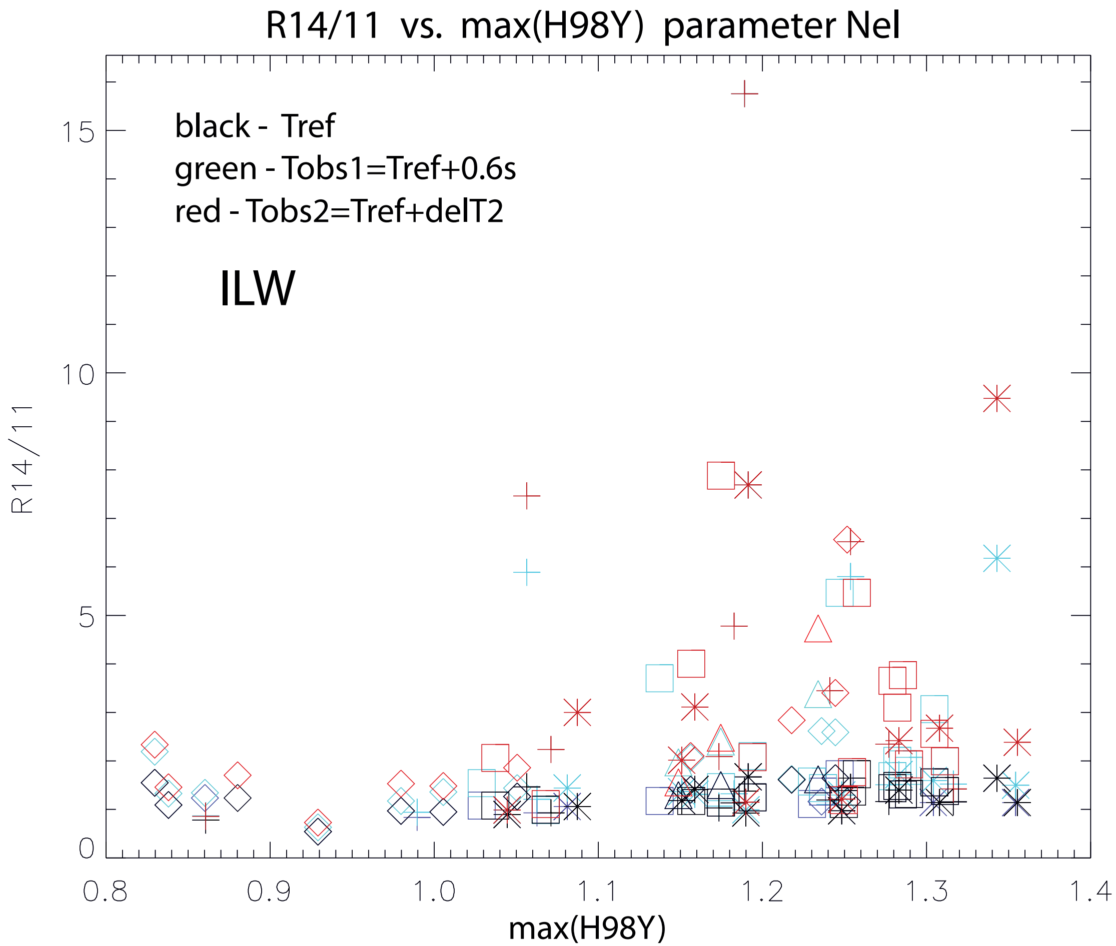
$$delZeff = ((ZefV+ZefH)|_{Tobs} - (ZefV+ZefH)|_{Tref}) /2$$

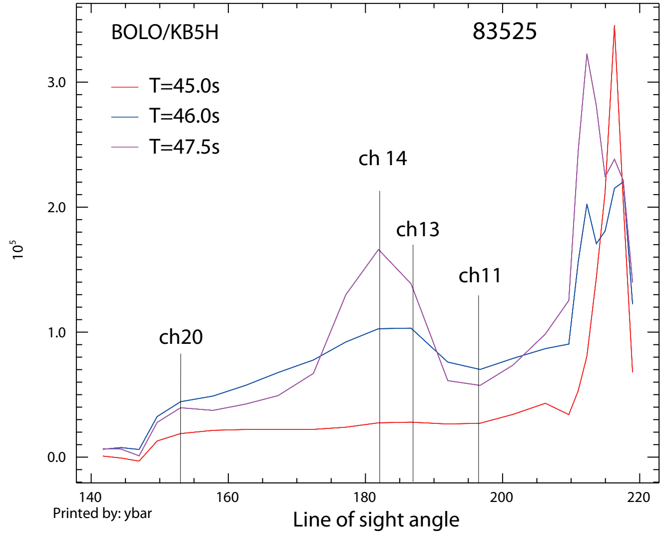


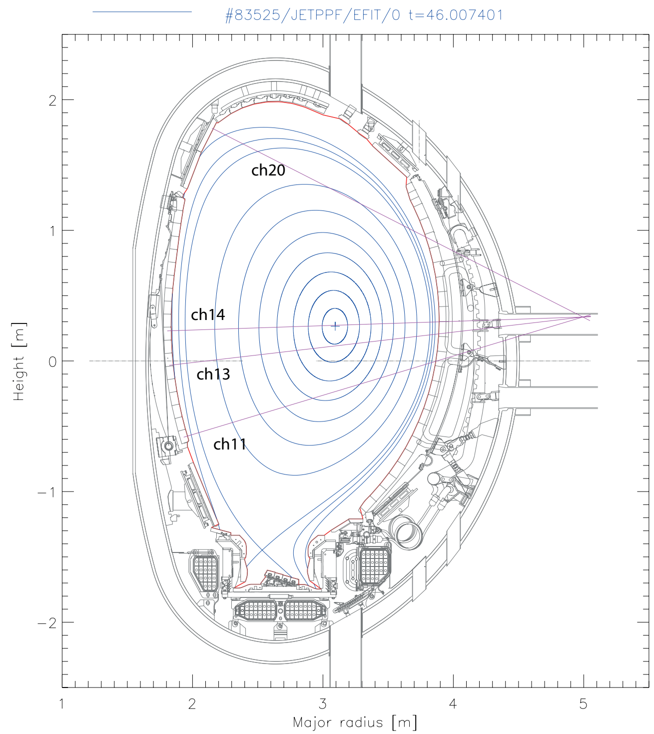
Core radiation measured by bolometer horizontal camera (BOLO/KB5H)

Peaking of radiation is characterised by ratio:

R14/11=BOLO/KB5H(ch14)/ BOLO/KB5H(ch11)

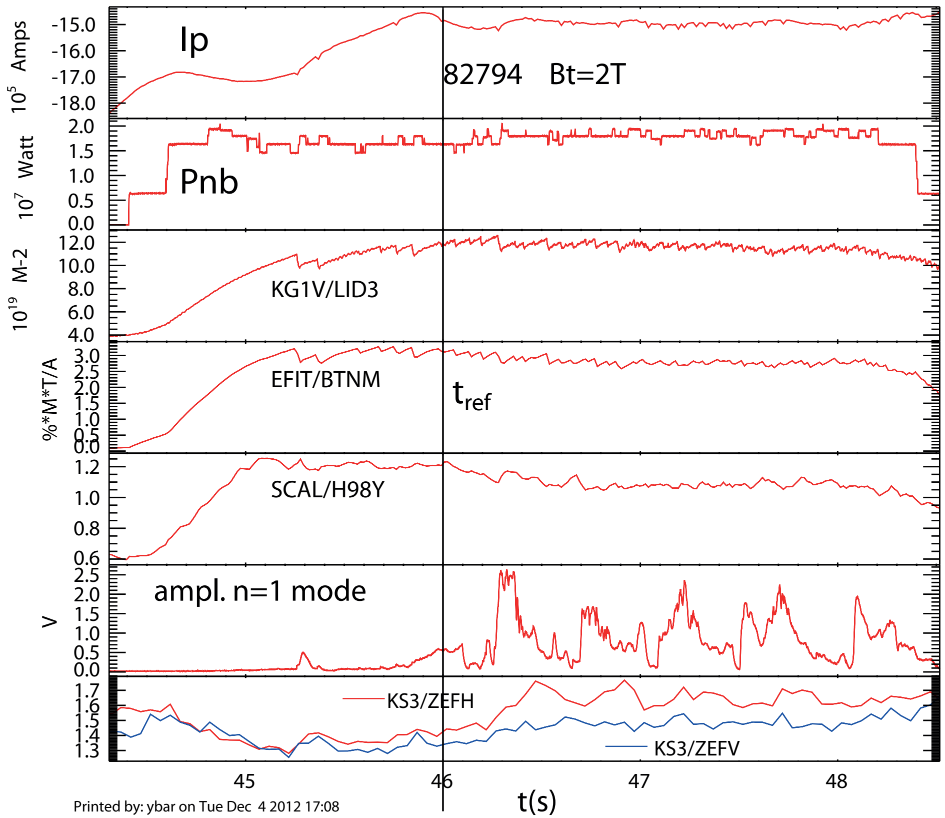


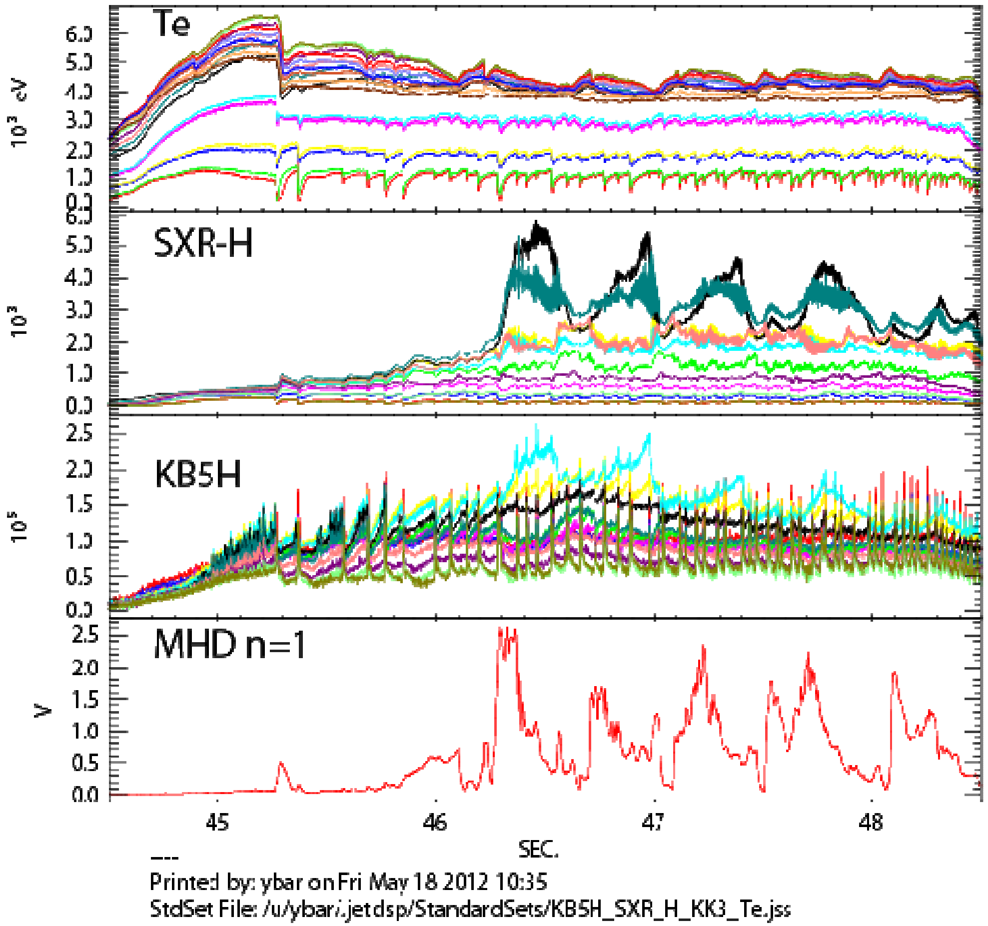




- Peaked radiation is caused by impurities
- What is the main impurity and its spatial distribution at the time of max(betN)?

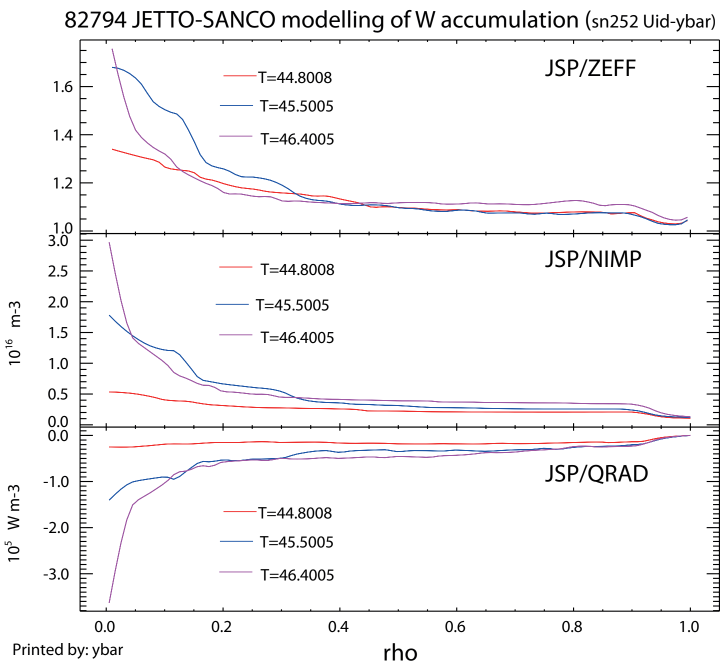
MHD, core radiation and impurities

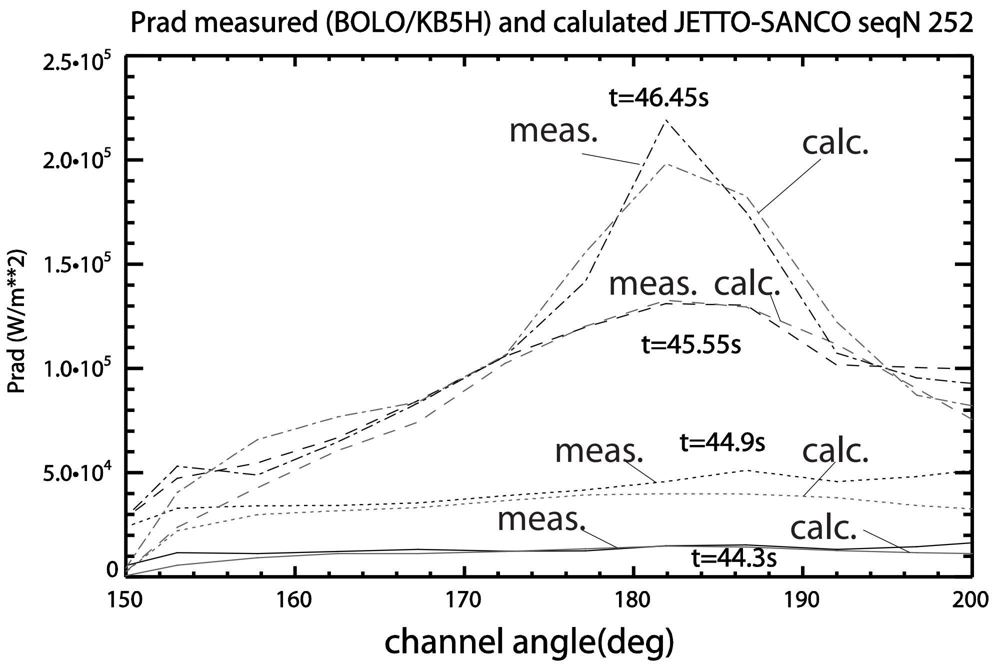




Case 1: Heavy impurity- W

JETTO-SANCO modelling of tungsten accumulation well reproduces measured radiation profiles





At t=45.9-46s, when betN (H98Y) reaches its maximum measured KS3/ZefH=1.4-1.5

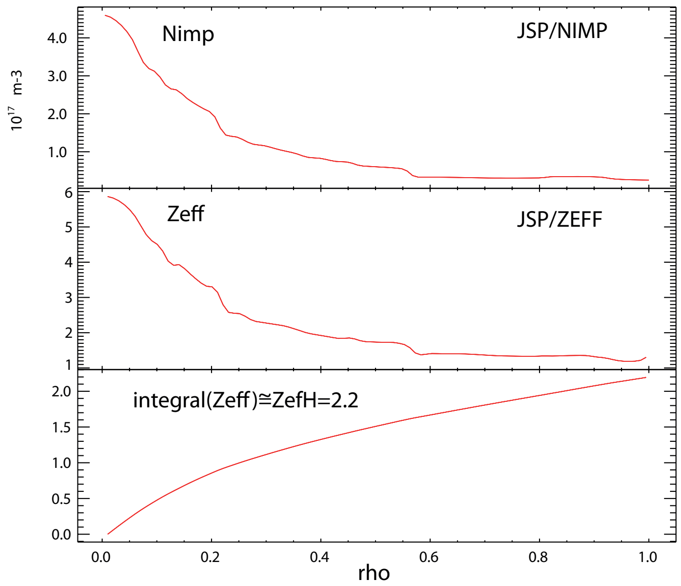
Modelled W concentration corresponds to Zeff=1.18

Is there any room for other heavy impurities?

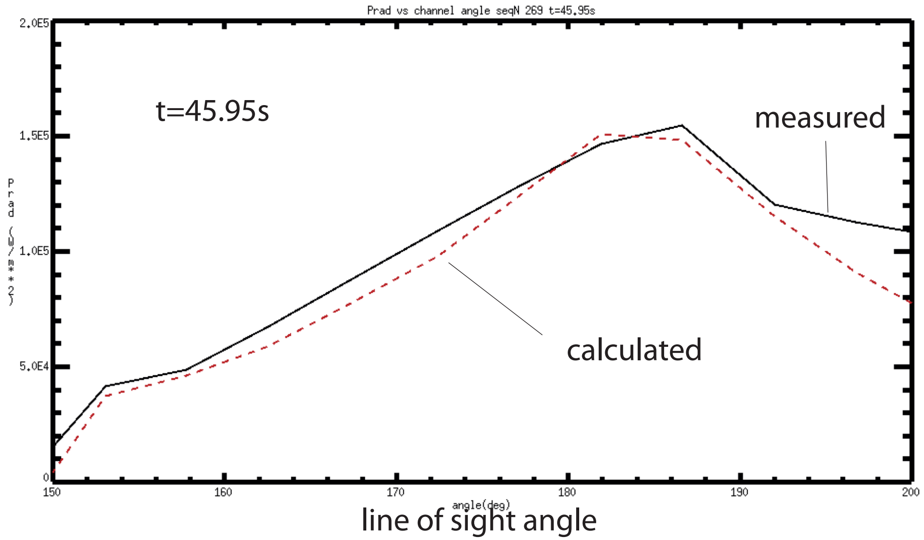
Case 2: Heavy impurity- Ni

JETTO-SANCO modelling of Ni accumulation well reproduces measured radiation profiles

82794 JETTO-SANCO modelling of Ni accumulation (sn269 Uid-ybar)



Prad measured (BOLO/KB5H) and calculated JETTO-SANCO sn269



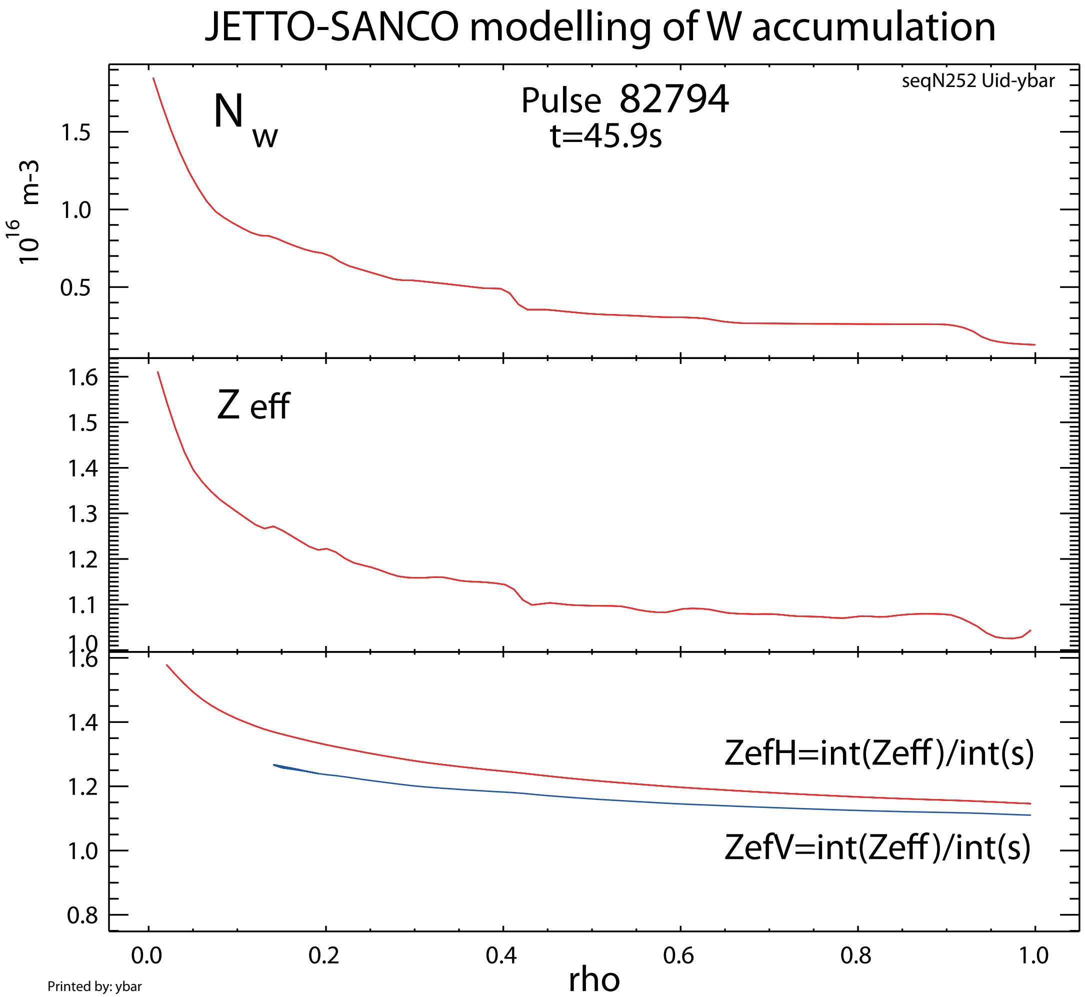
At t=45.9-46s, when betN (H98Y) reaches its maximum measured KS3/ZefH=1.4-1.5

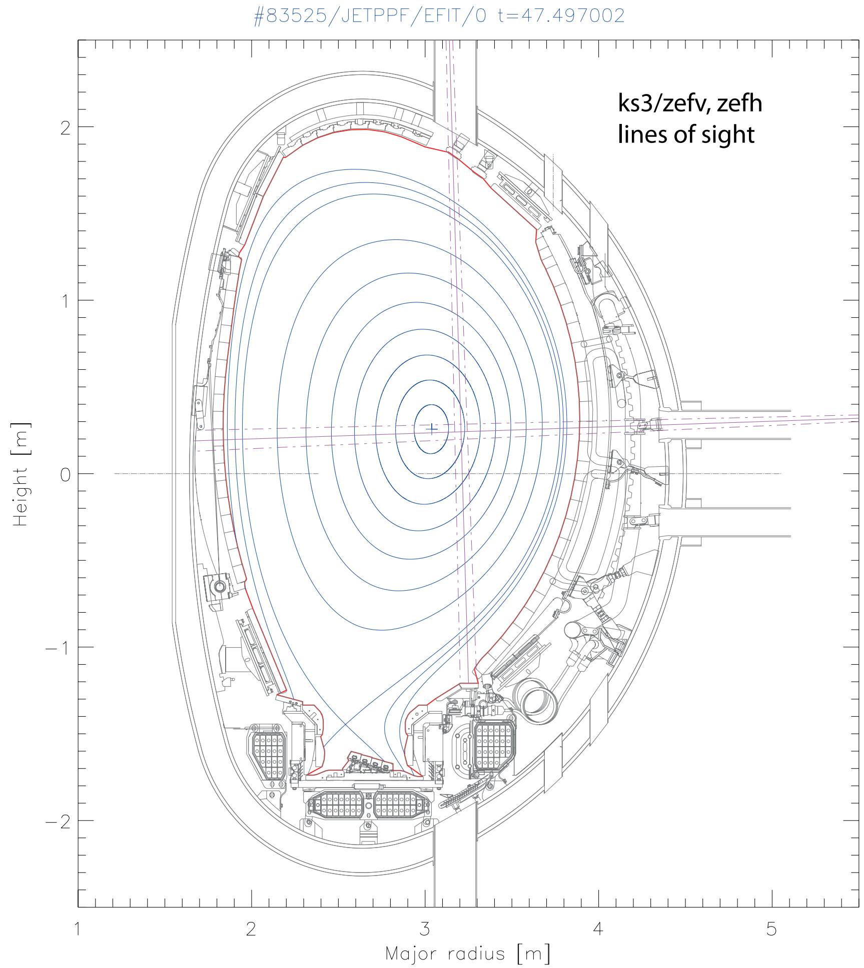
Only 35-40% of modelled Ni would introduce full measured Zeff

Conclusion: in the absence of light impurities 77% of W and 23% of Ni account for all measured Zeff and core radiation

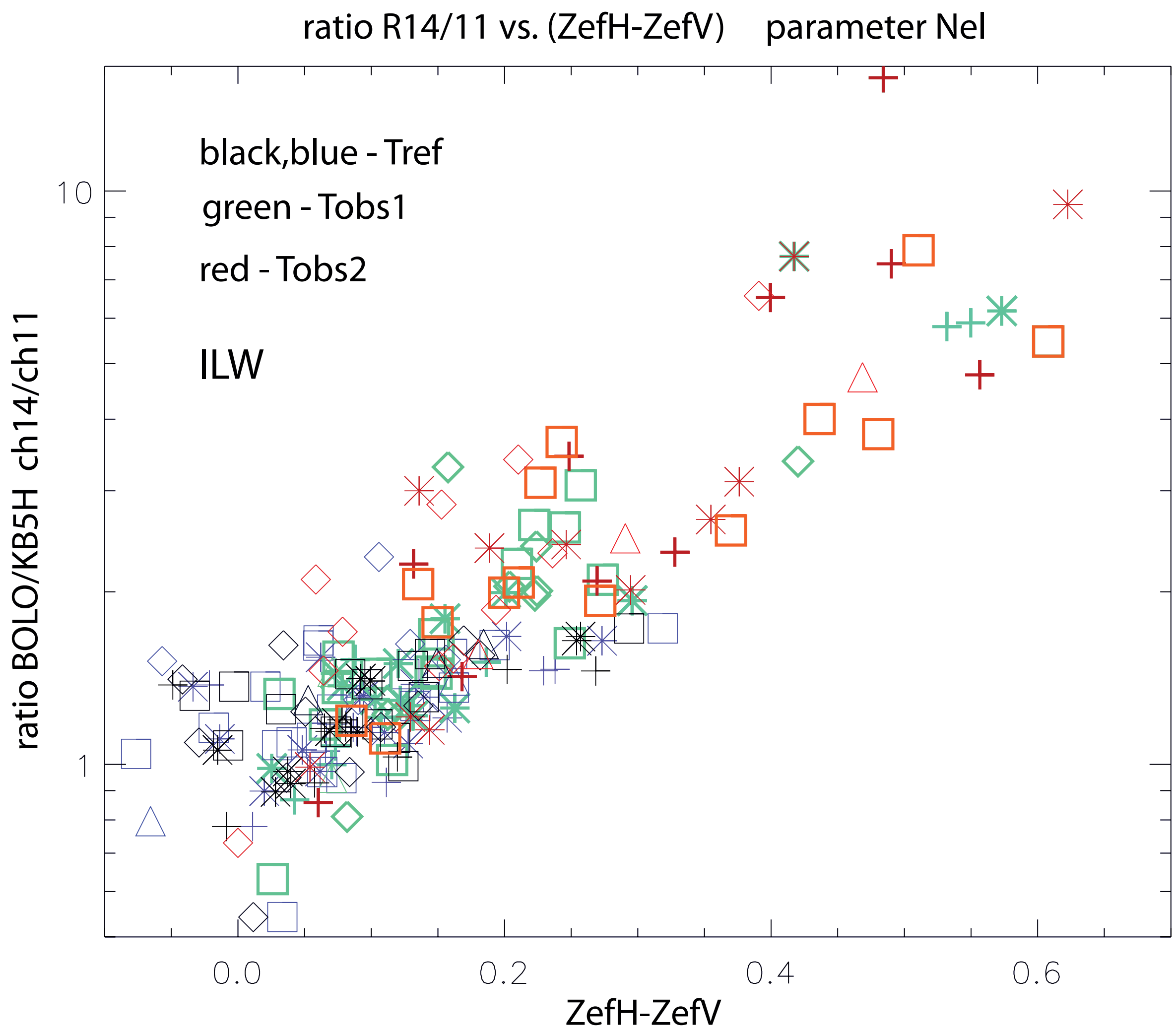
Light impurities should increase W and reduce Ni contribution

Peaking of Zeff introduces difference in KS3/ZefH and KS3/ZefV signals





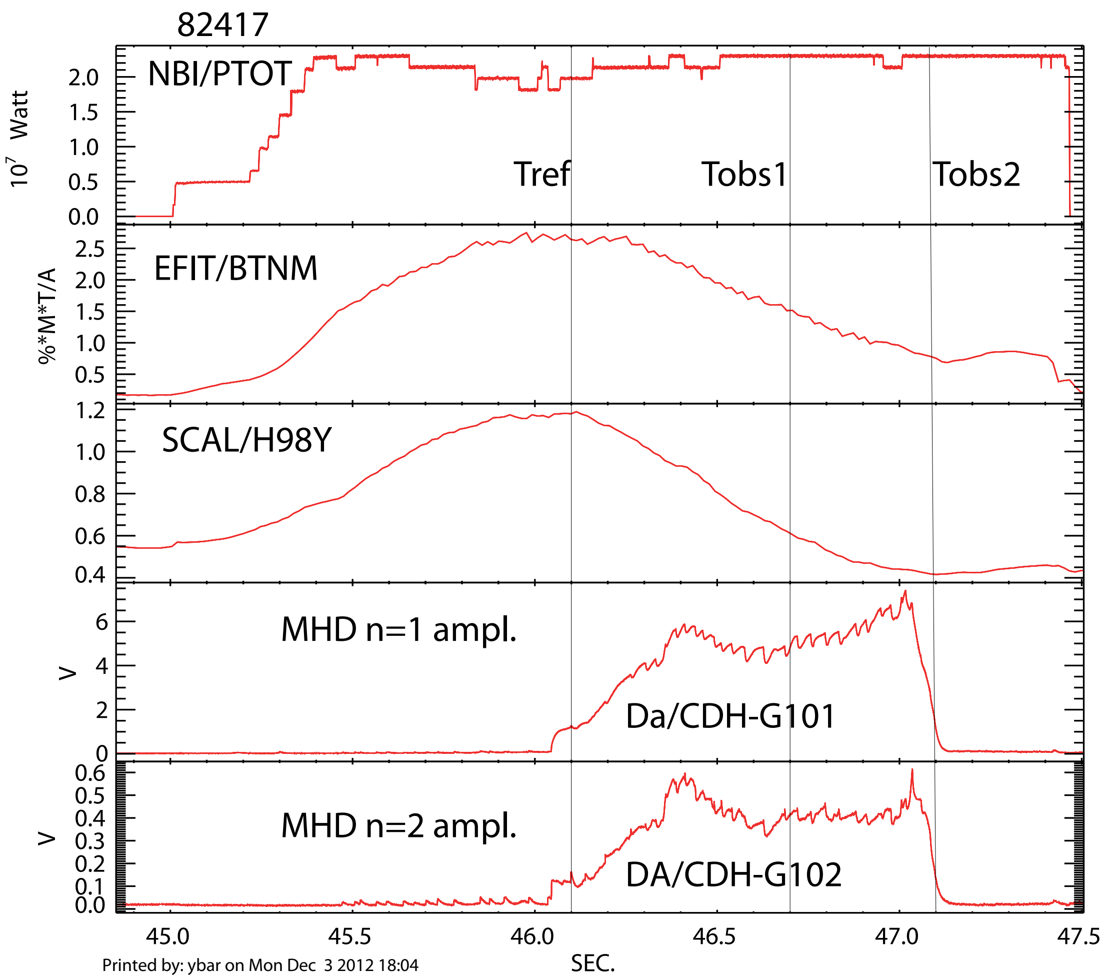
Correlation between radiation peaking and difference in measured ZEFH and ZEFV

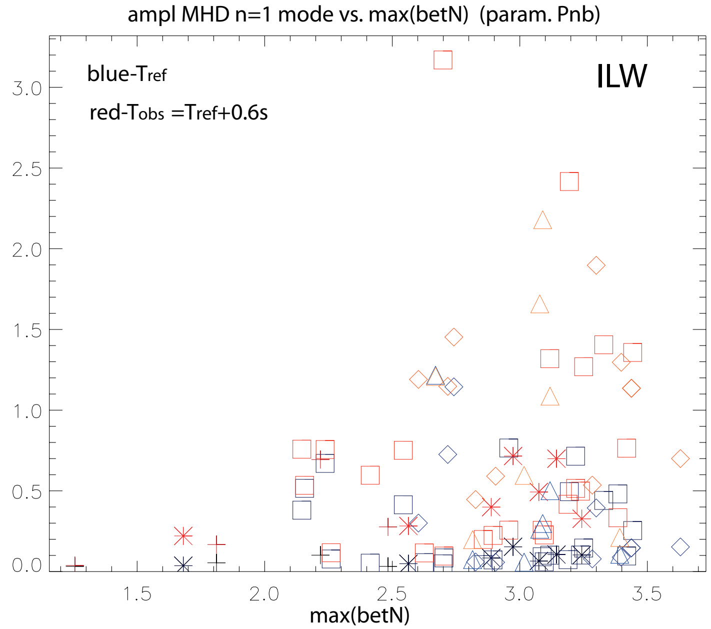


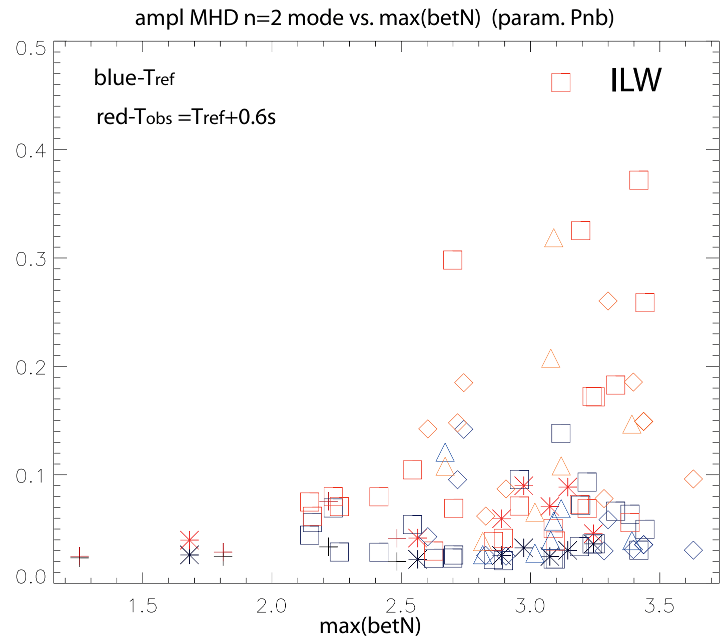
Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement

Amplitude of n=1 and n=2 mode at

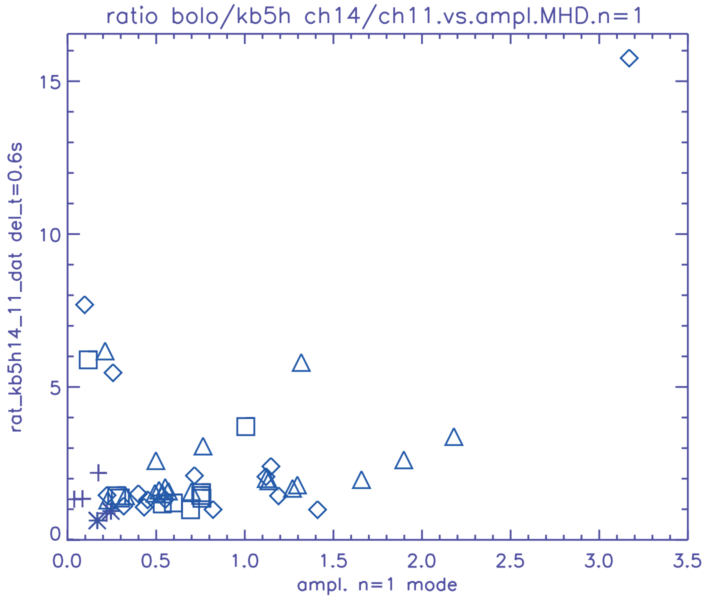
Tref at max(betN) and Tobs=Tref+0.6s in hybrid pulses with ILW





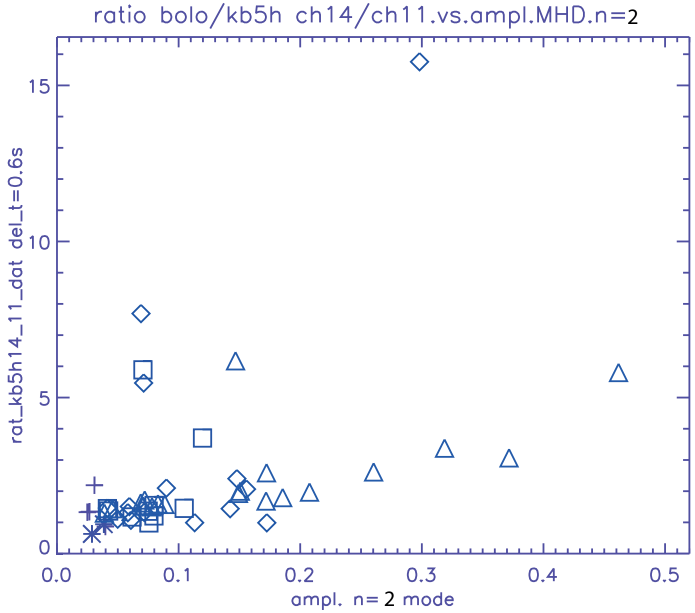


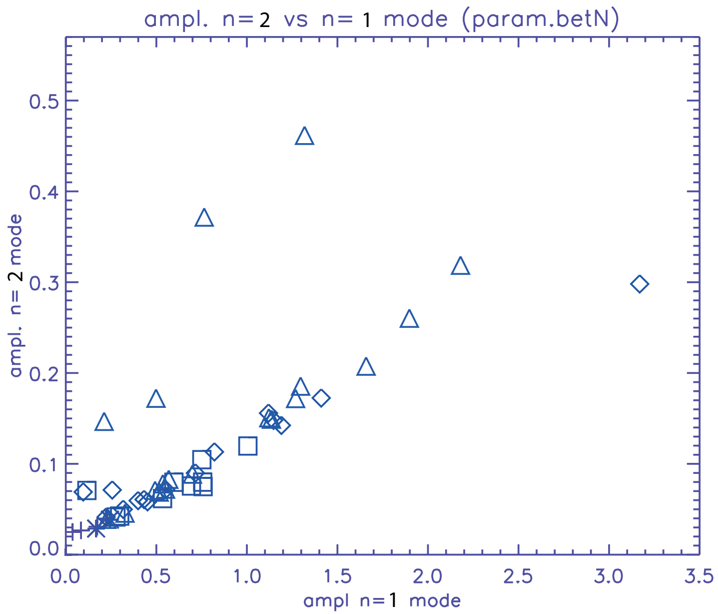
Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement

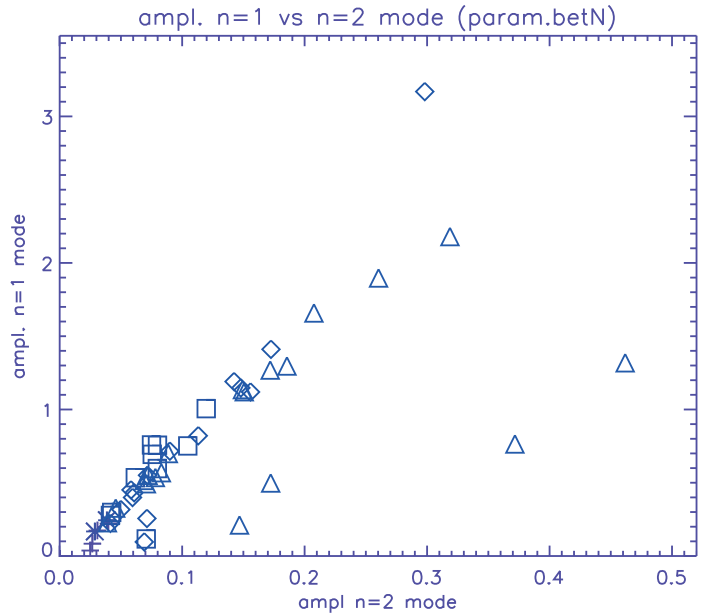


Correlation between radiation peaking and MHD at

Tobs=Tref+0.6s







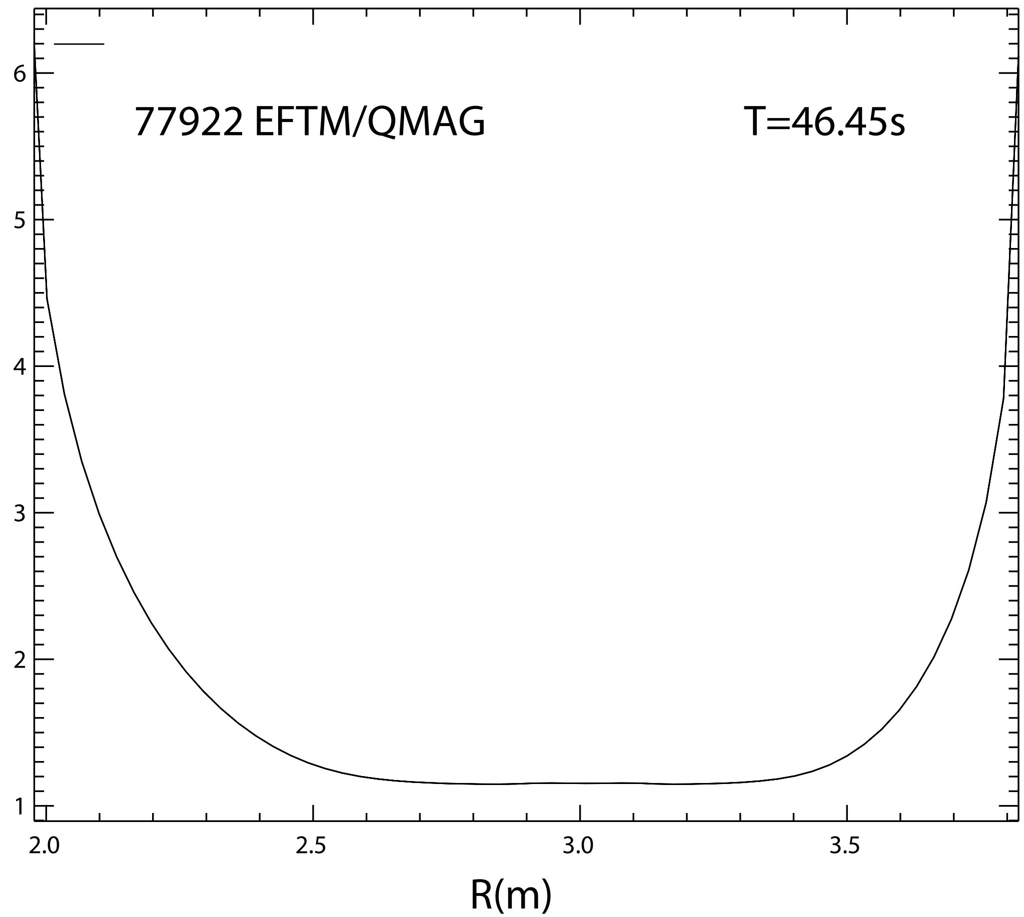
Intermediate summary:

- Impurity (W) accumulation and radiation peaking in the core is observed in all hybrid pulses with improved confinement H98Y>1.1
- MHD is stronger in high beta hybrid pulses with improved confinement H98Y>1.1 with ILW
- MHD, impurity and radiation correlate with confinement degradation in all hybrid pulses at H98Y>1.1 with ILW

WHY ?

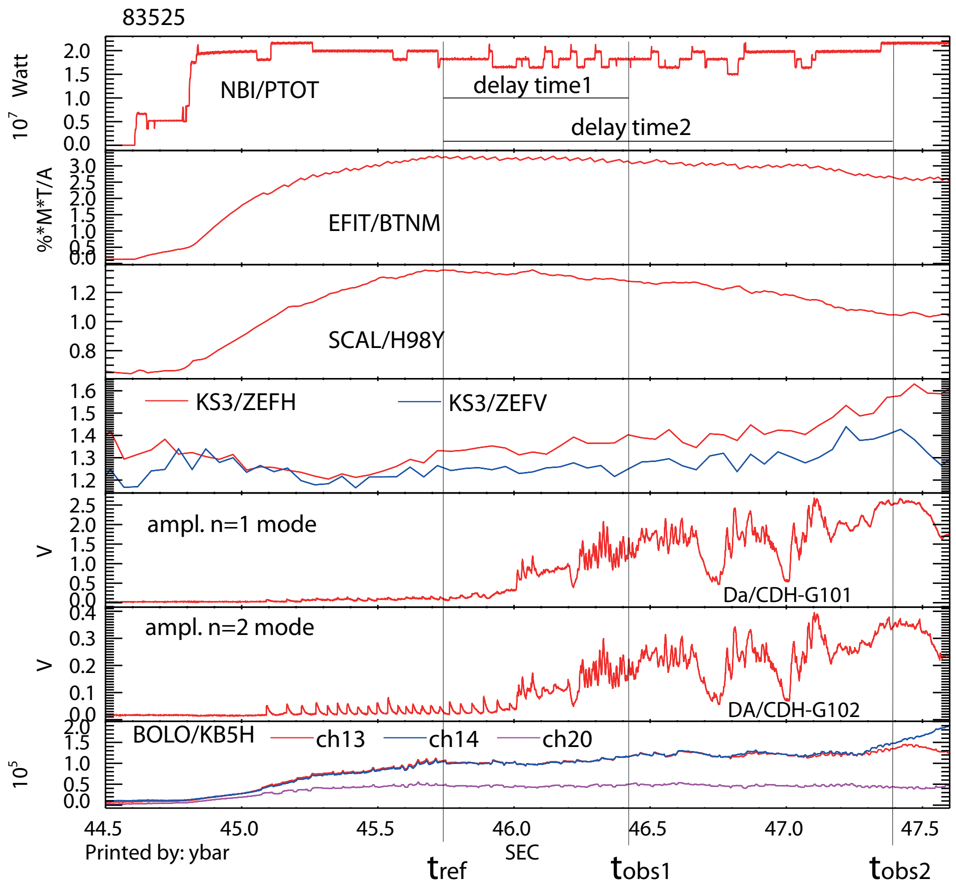
- A confinement in Hybrid pulses strongly depends on the shape of the target q-profile.
- The target q-profile is formed during the current ramp-up phase
- The q-profile with a broad low shear region near q=1 in the plasma core and large shear at the edge provides condition for achieving highest confinement, betN and bootstrap fraction

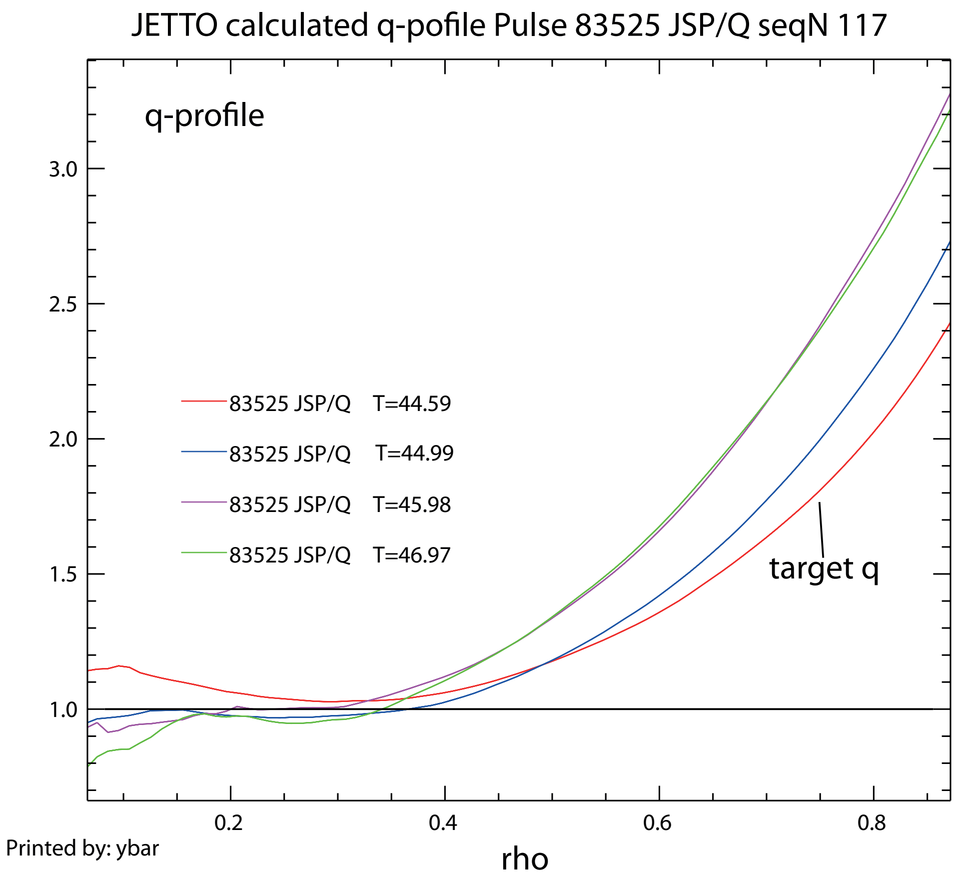
Almost ideal q-profile



Typical case:

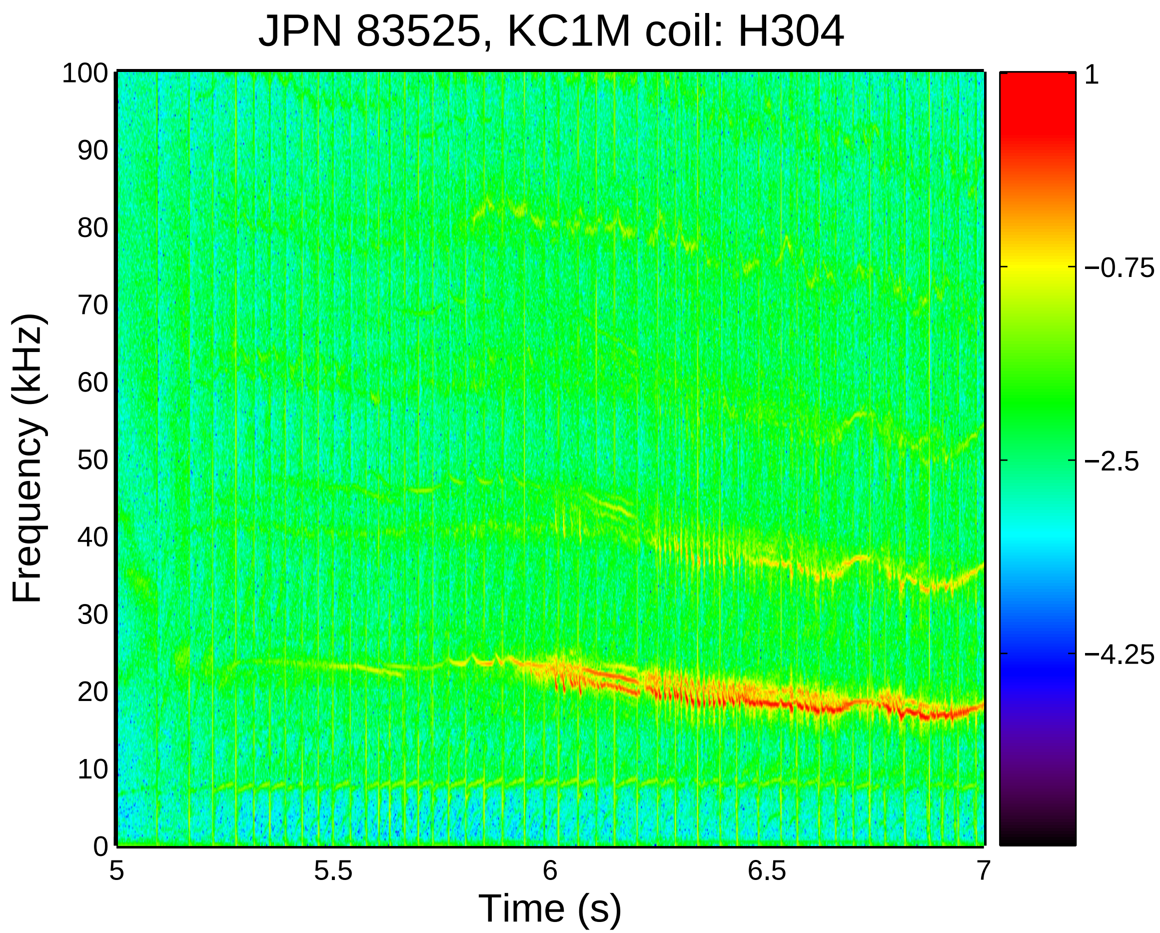
- Almost ideal target q profile has been formed
- The q remains around q=1 in the core for a long time.
- Such profiles are prone to MHD.

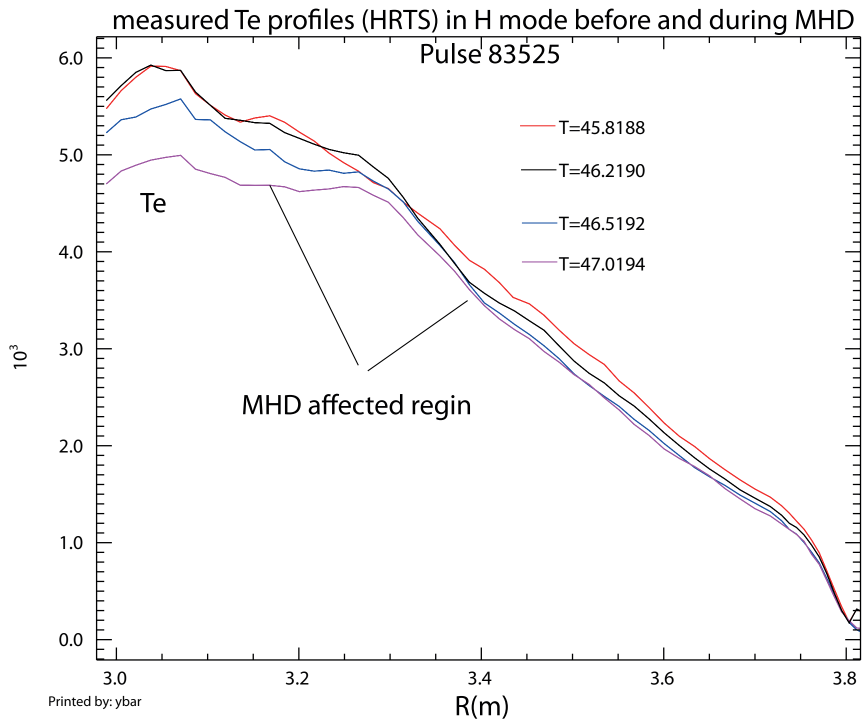




Typical case:

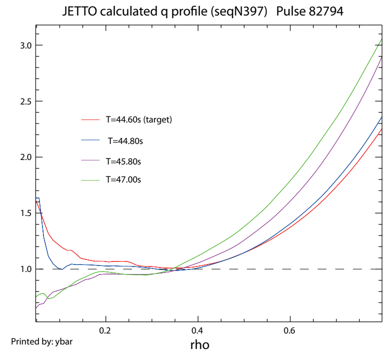
- Tearing modes may be triggered in the presence of impurities
- MHD (possibly tearing mode) cause temperature perturbation and confinement degradation

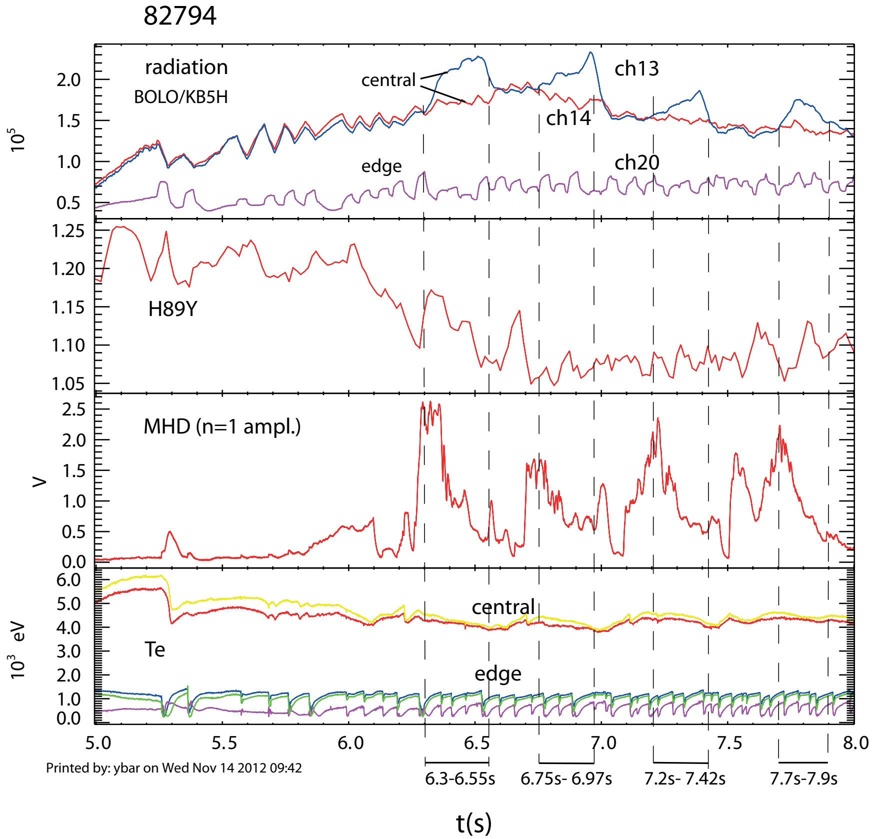


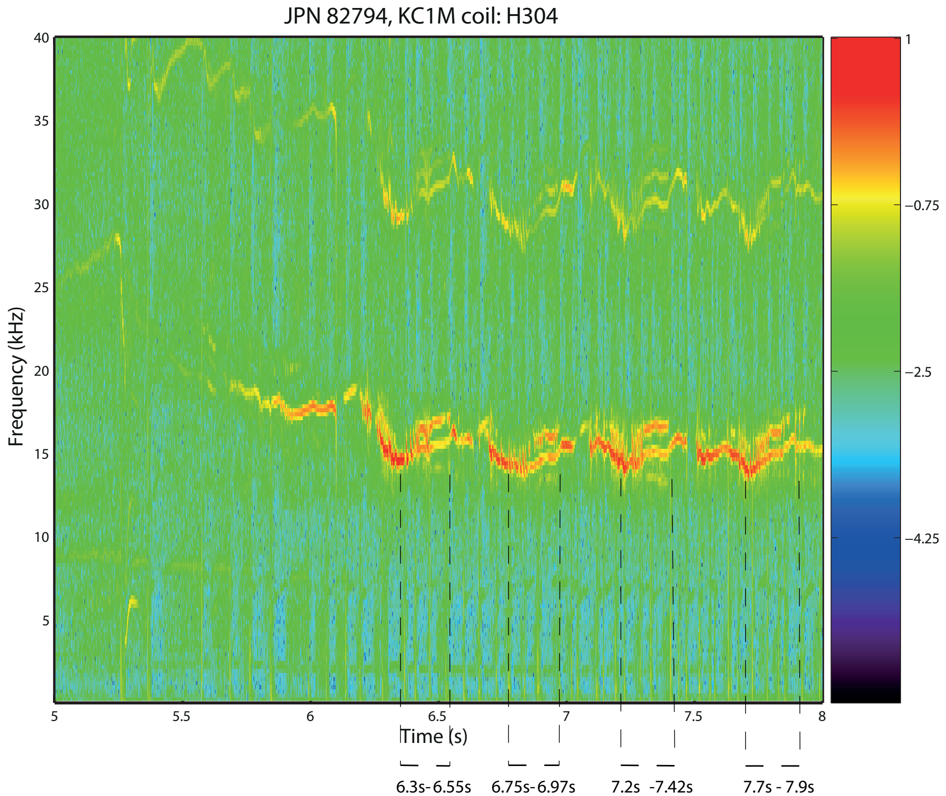


Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement

- The q-profile with wide flat region around q=1 has been formed and maintained during high power phase.
- Such q profile is prone to MHD
- Periodically the q-profile crossed q=1 in several points
- Double /triple tearing-like modes have been excited
- Tearing modes caused strong impurity and radiation peaking

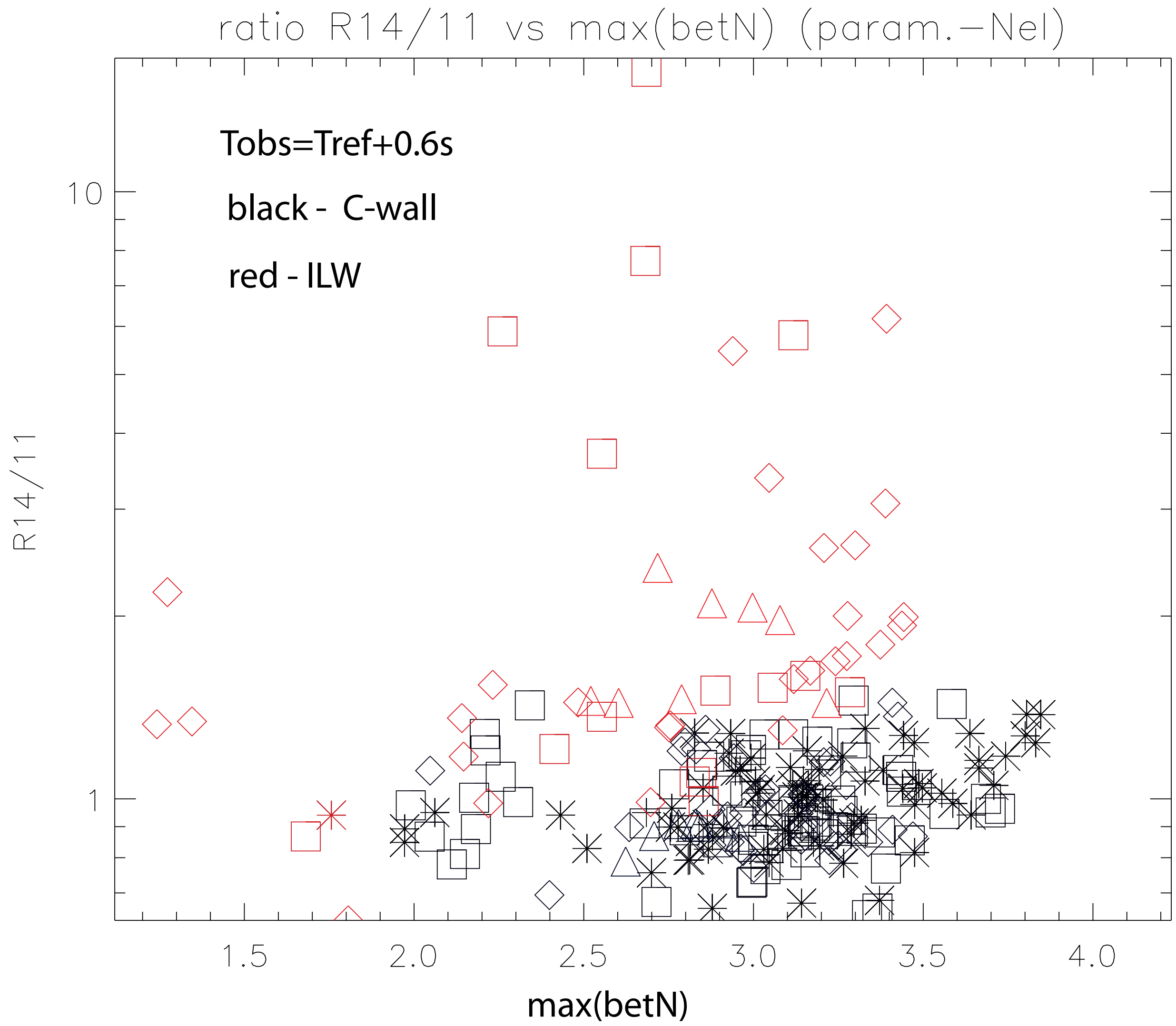






What is the difference between ILW and C-wall hybrid pulses ?

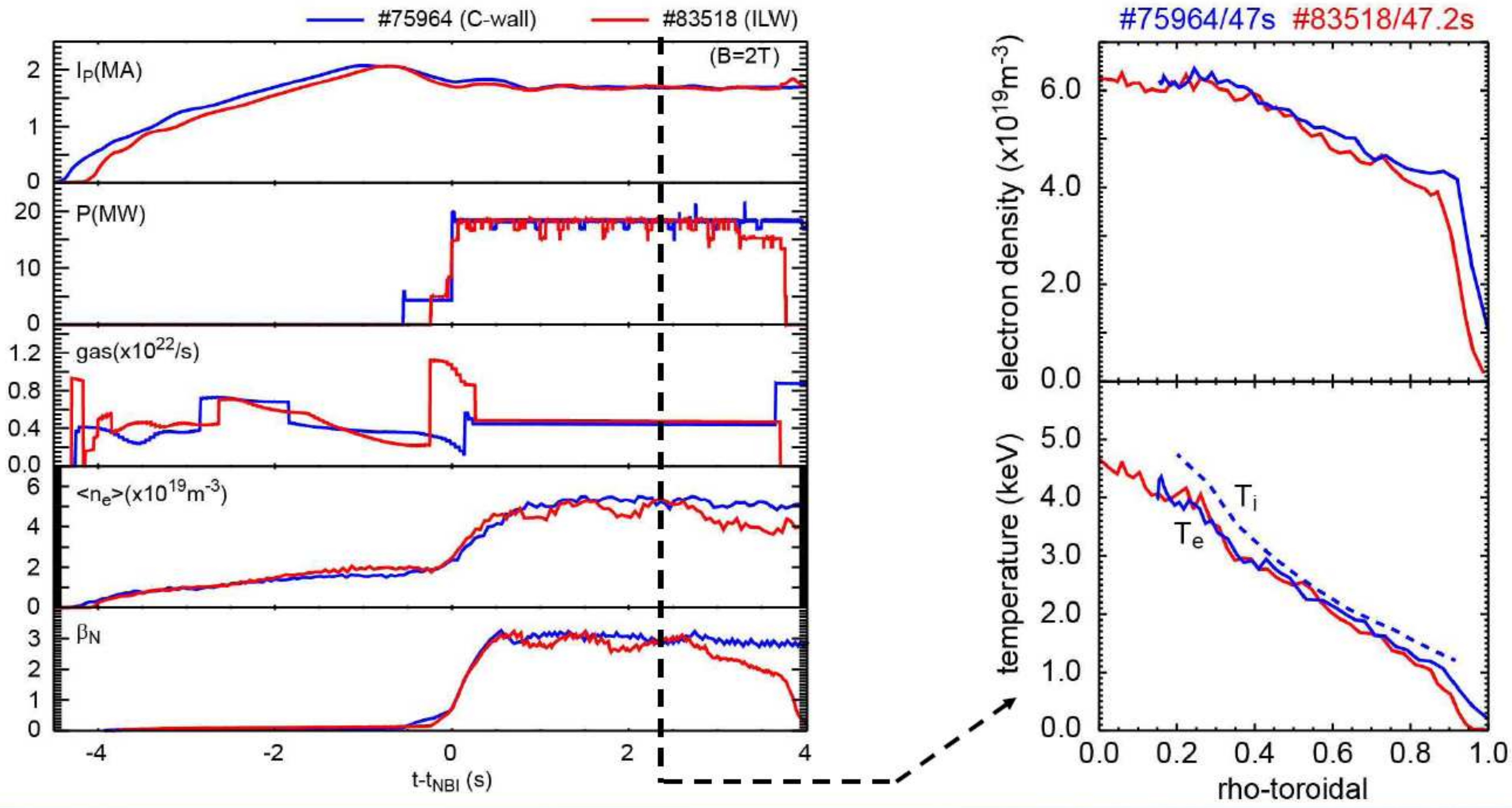
Radiation peaking in hybrid pulses with C-wall and ILW



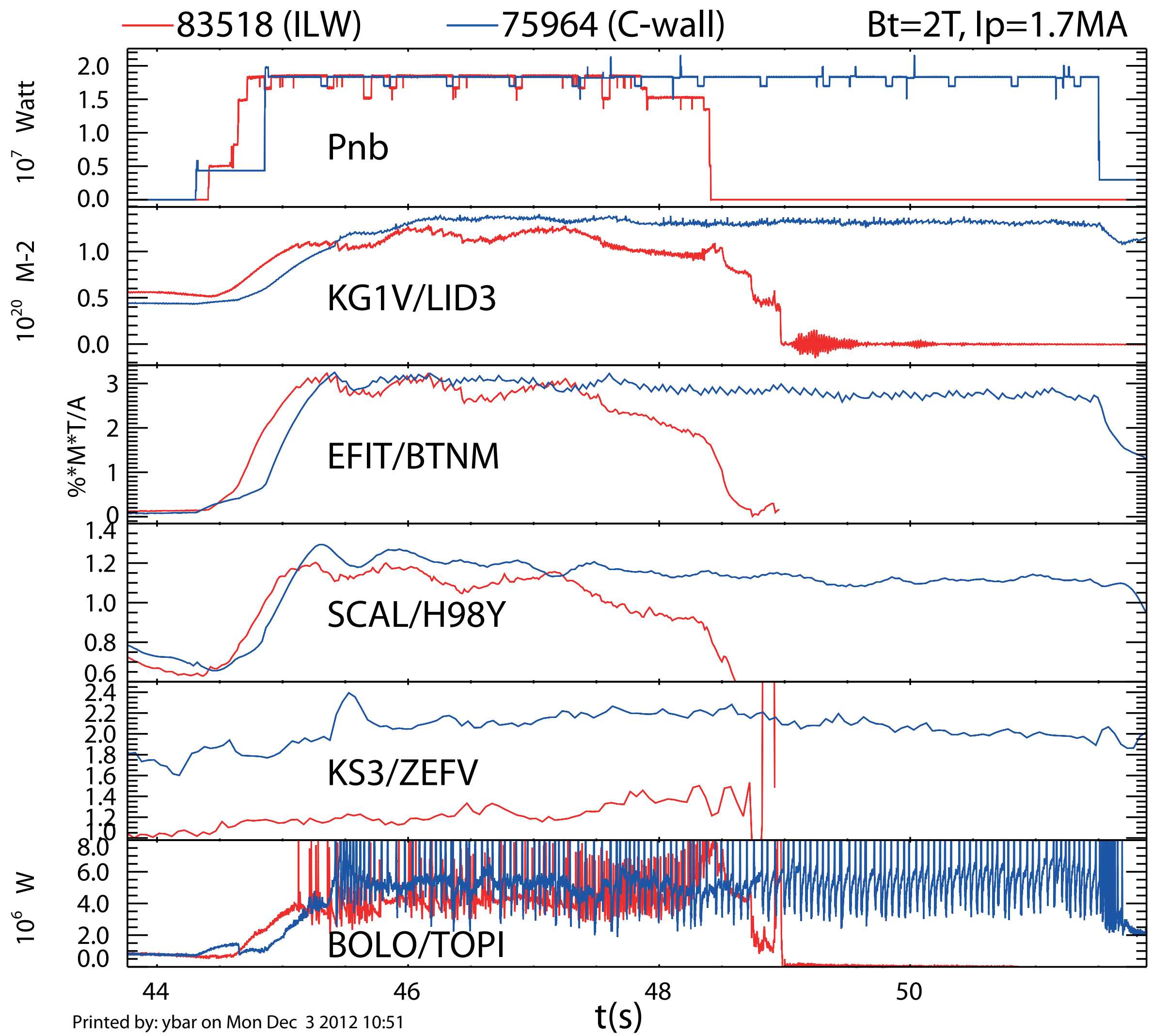
- no peaking in C-wall pulses
- strong peaking in ILW

C-wall / ILW comparison : High δ

- High δ hybrid with same gas, power, I_P, B_T… but ILW using tile-5
- Similar performance and profiles, but less stable with ILW due to core radiation



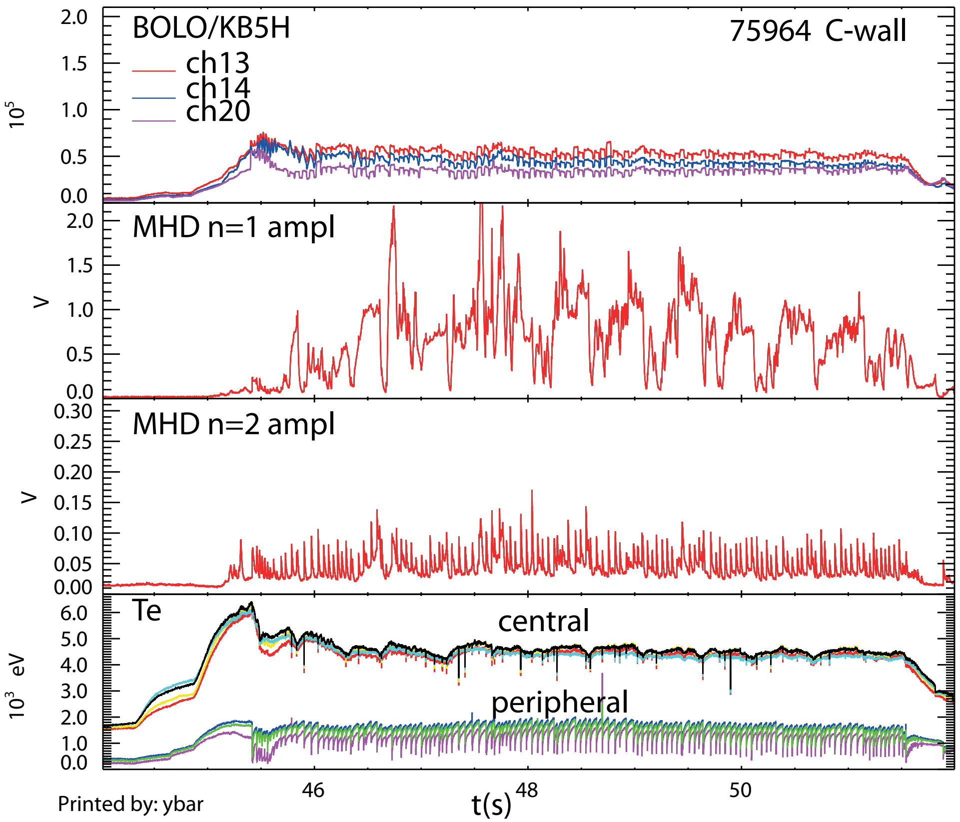
Comparison of ILW and C-wall case

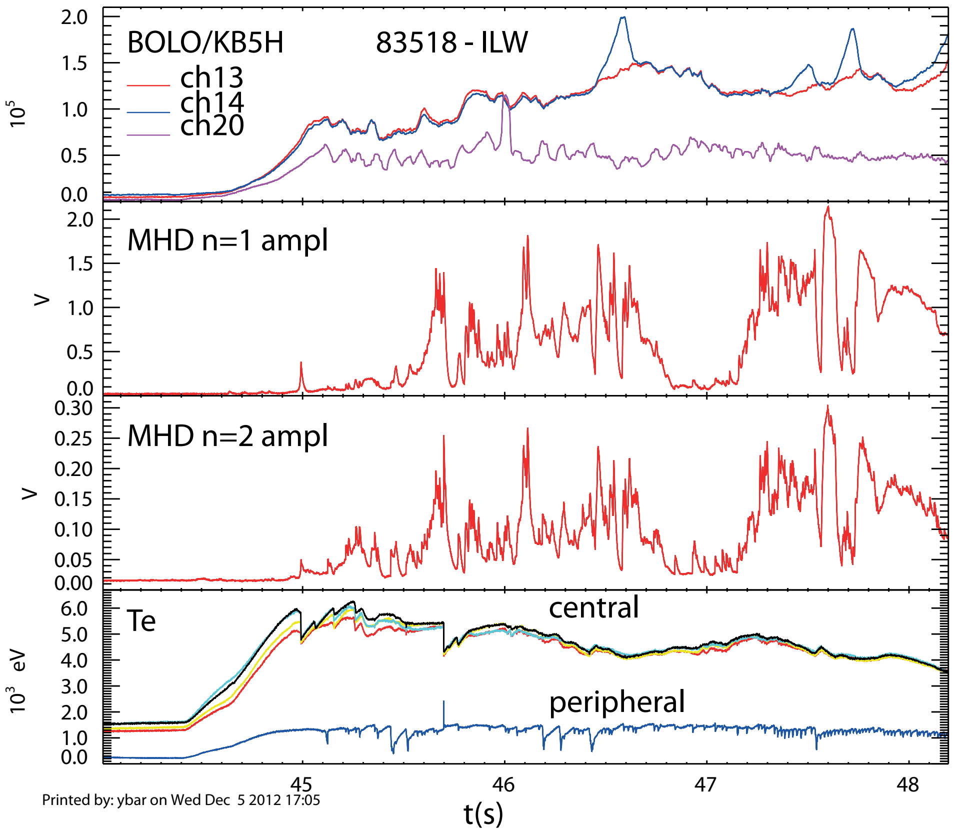


Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement

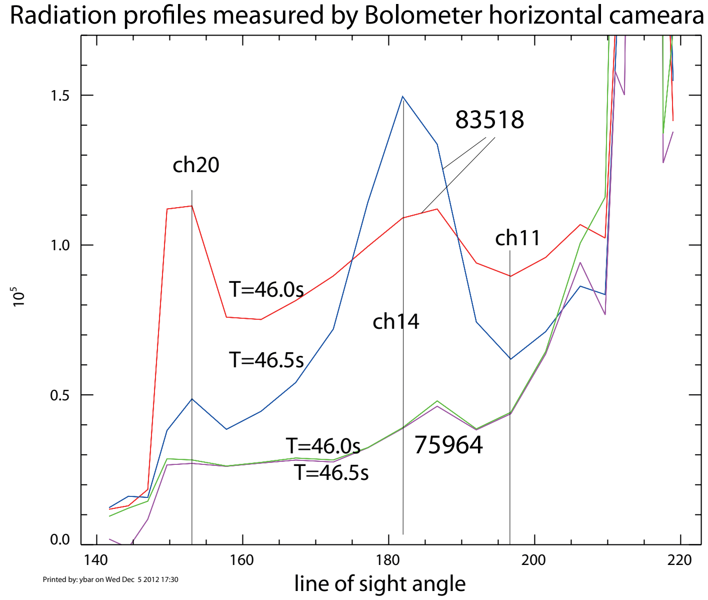
C-wall
MHD –benign
Core radiation - small
Good performance and quasi-steady state achieved

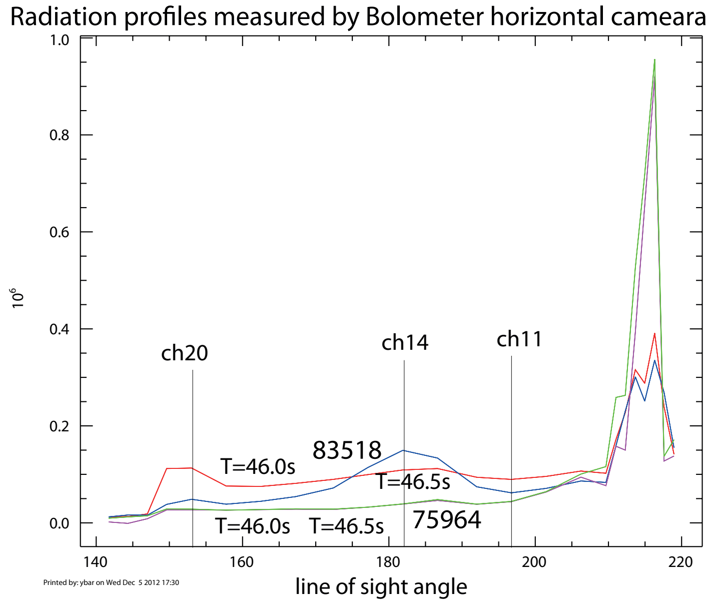
ILW
MHD affect radiation, Te
Core radiation - large
Confinement is degraded by MHD
Pulse terminated by radiation

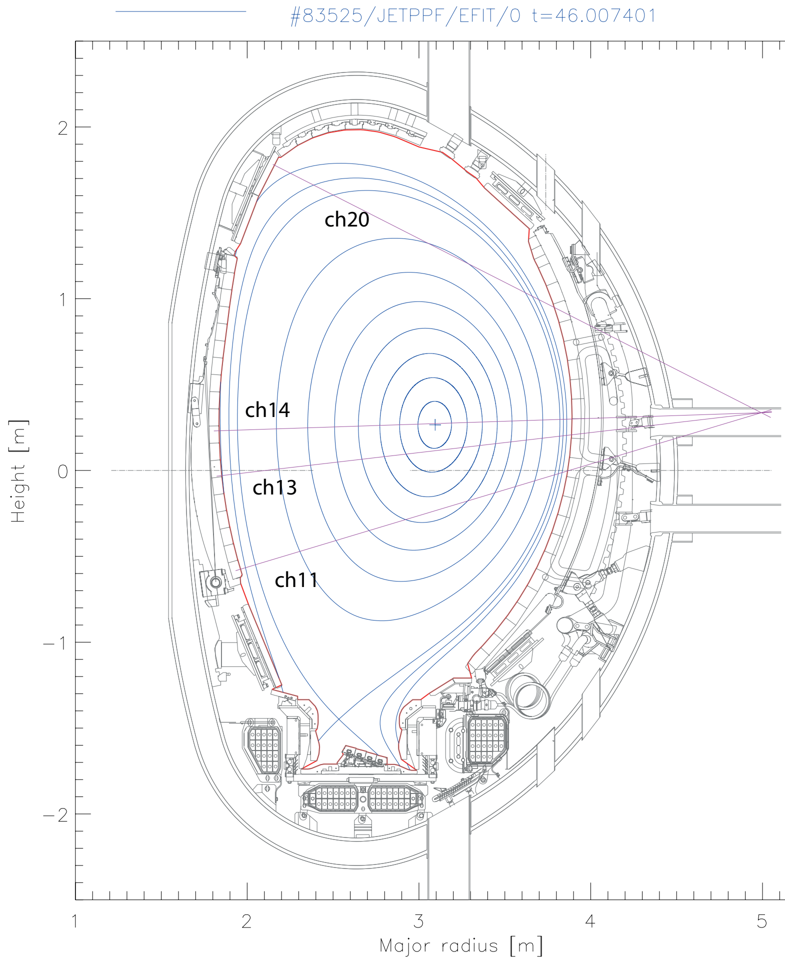




Core radiation is much larger and divertor radiation is much smaller in hybrid pulses with ILW than in C-wall

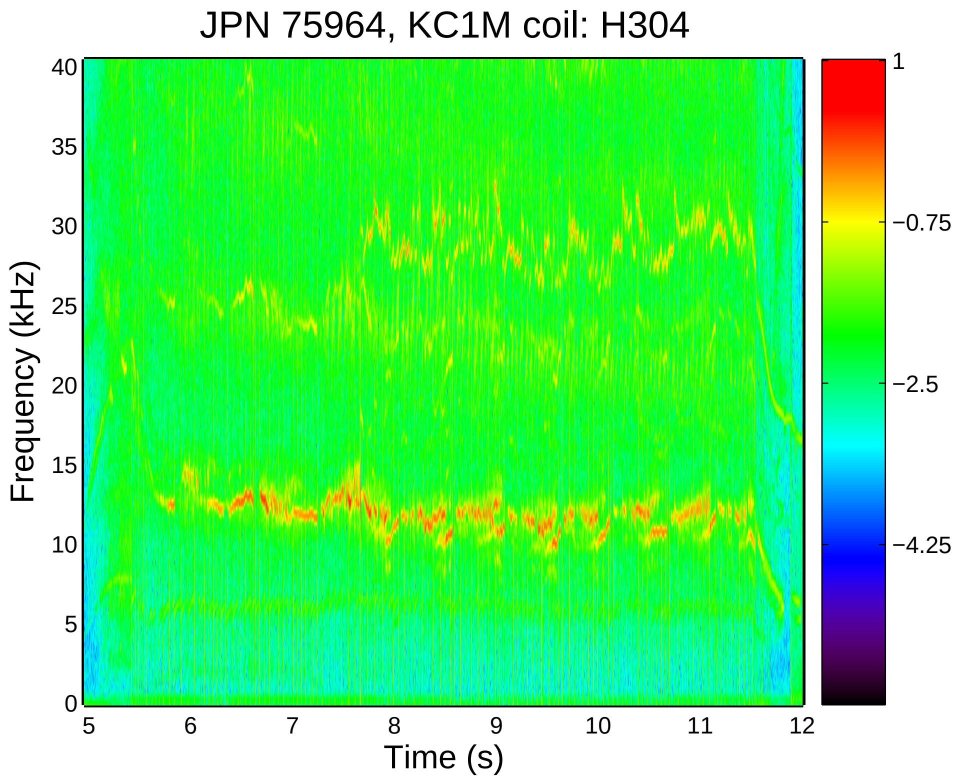




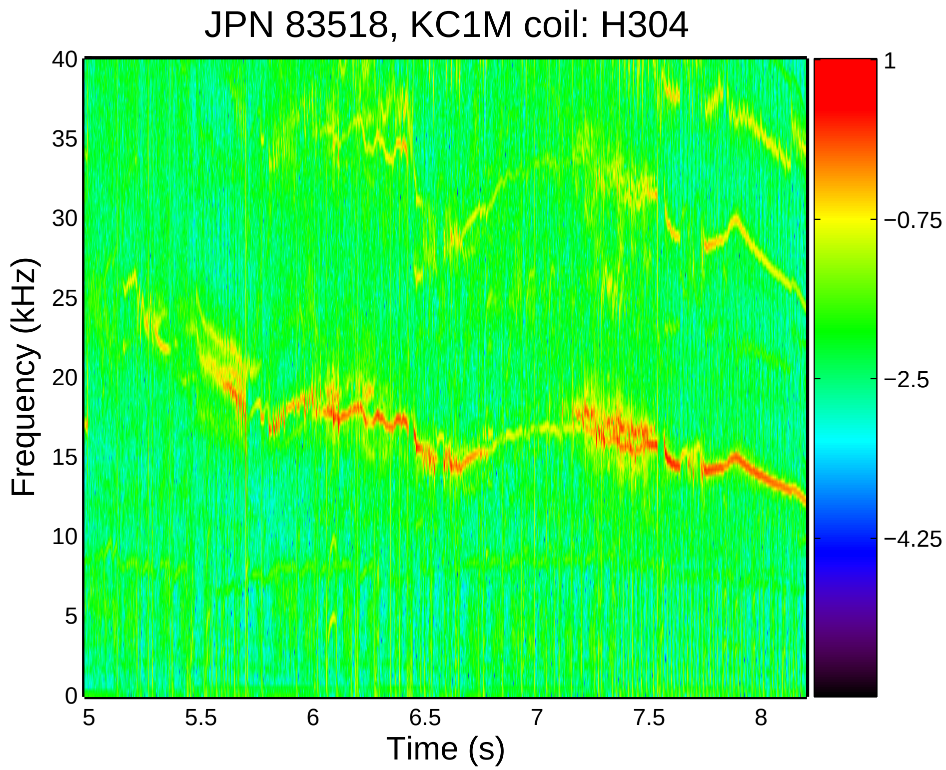


Database for hybrid pulses with ILW: MHD, impurities, radiation, confinement

- MHD frequency split may indicate a formation of tearing-like modes in ILW hybrid pulses. Tearing modes are most damaging for confinement and impurity peaking
- MHD frequency reduction may indicate the toroidal rotation slowing down in ILW



C-wall

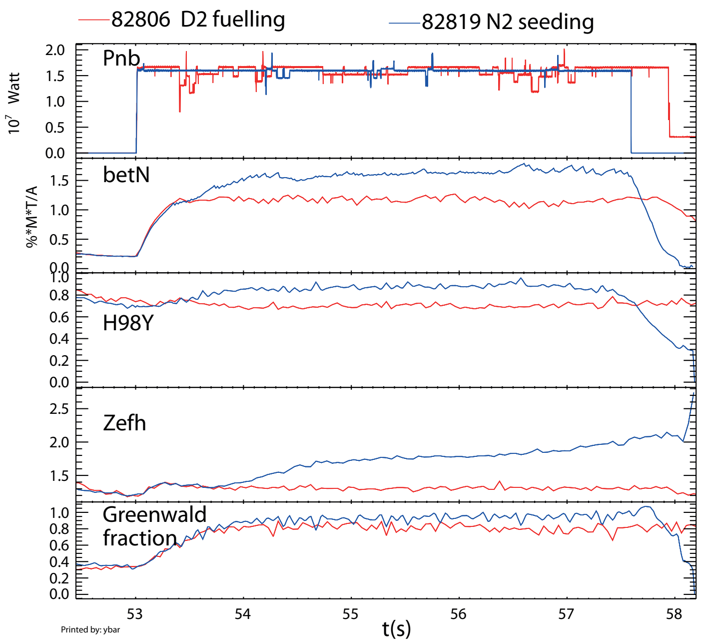


ILW

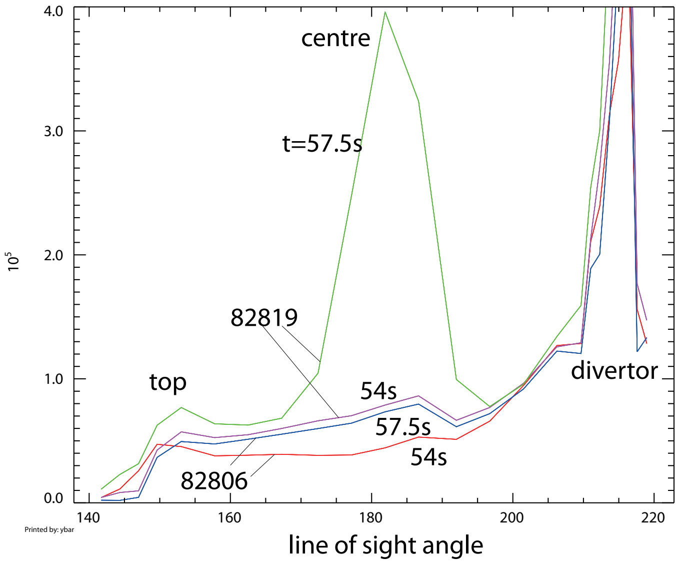
Remark on the difference between ILW and C-wall

- There are dozens of high betN quasi-steady state hybrid pulses with good confinement with C-wall
- MHD causes significant confinement degradation in all high betN pulses with ILW
- MHD is transformed from benign kink mode in C-wall to destructive tearing-like modes with ILW
- Heavy impurity content (W) is one of the main differences between C-wall and ILW
- Peaking of Zeff is a plausible cause for changing MHD behaviour

Comparison with baseline scenario



Radiation profile measured by horizontal bolometer camera



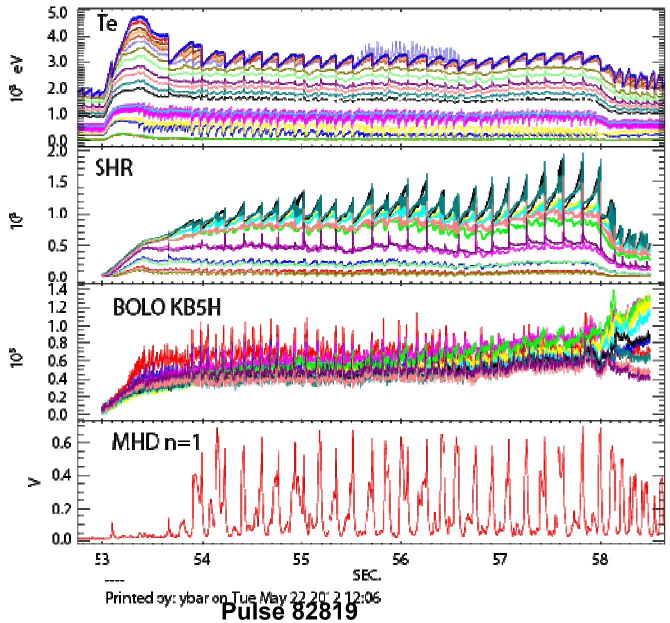
W accumulation and peaking stronger in pulses with higher confinement in baseline as in hybrid pulses

betN - relatively small

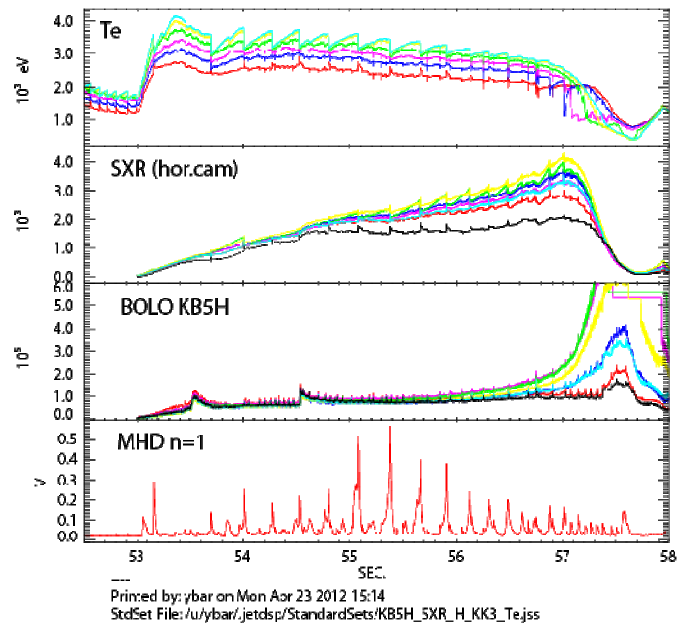
MHD does not appear to be a problem

The q-profile profile in the core and betN level are the main differences between hybrid and baseline defining MHD behaviour

Pulse 82806



Pulse 82819



- W accumulation in the core continues until radiative collapse in baseline scenario pulses with good confinement
- There is no confinement degradation due to strong MHD (in some pulses such MHD occurs during the collapse)

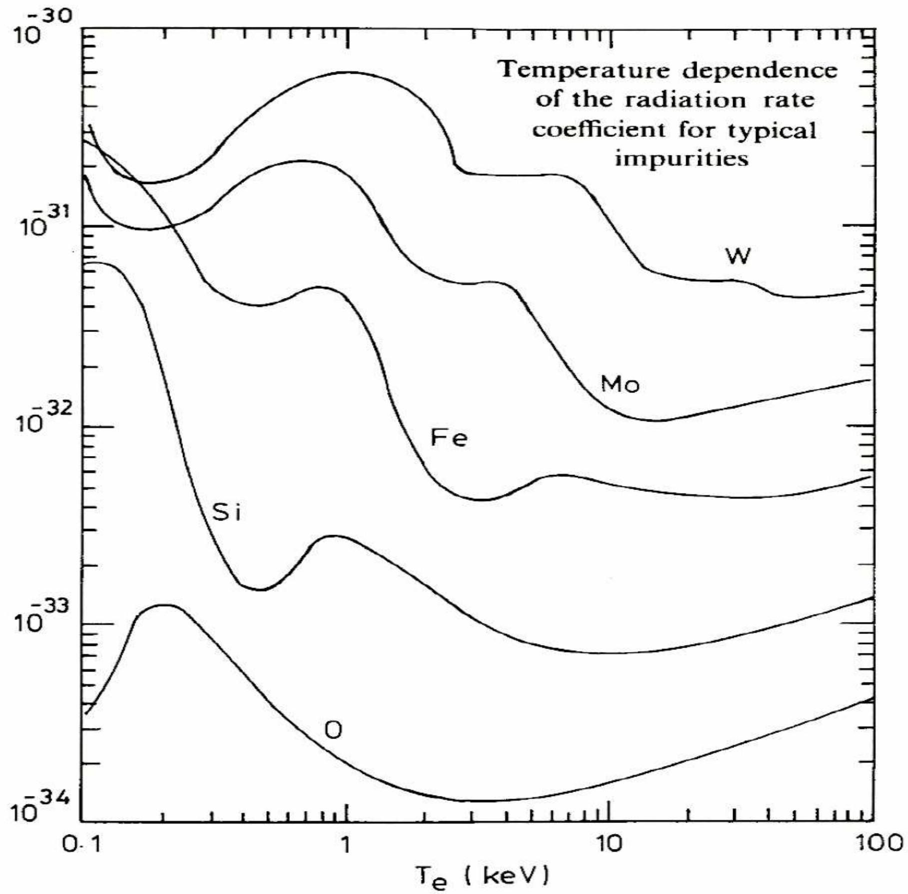
Conclusions:

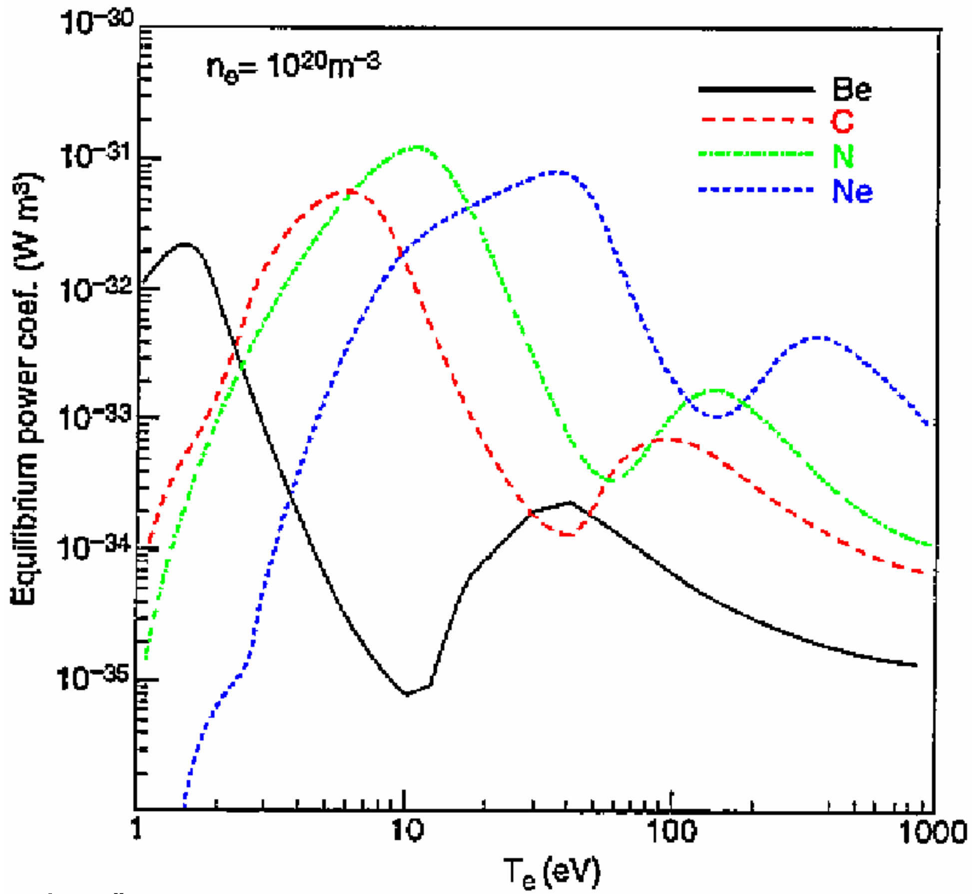
- Tungsten is accumulated in all ILW hybrid pulses if confinement is good (H98Y>1.1) causing increase in the core radiation.
- MHD is excited in all ILW hybrid pulses with high betN and good confinement due to a combination of flat q profile (q~1) and presence of heavy impurities in the core
- Benign kink-like mode (observed in hybrid pulses with C-wall) is transformed to tearing like mode (Fishsbone-?) in the presence of heavy impurities (W) in ILW.
- Such MHD cause betN and confinement degradation and stronger heavy impurity peaking near magnetic axis.
- Further W accumulation in the core (h.p. with ILW) is reduced due to the confinement degradation and a quasi-steady state regime is possible at the reduced confinement and betN
- W accumulation in baseline scenario with ILW does not cause excitation of destructive MHD until irreversible radiative collapse

Tungsten accumulation must be reduced using:

1) Beryllium evaporation. There is positive result from first tests
2) W screening by light impurities (first result of the modelling is available).
3) Application of central ICRH heating.

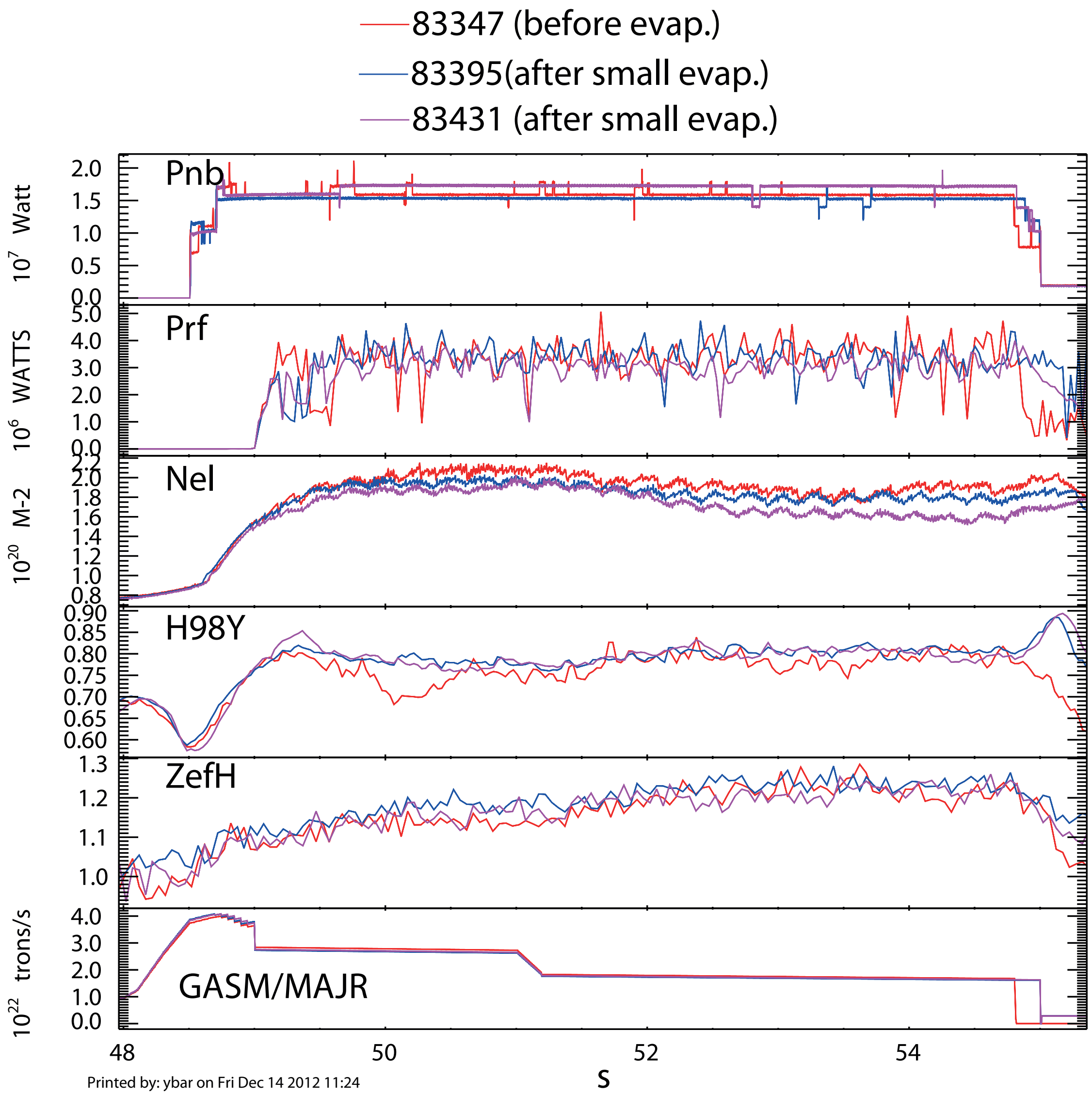
Radiation rate of heavy and light impurities





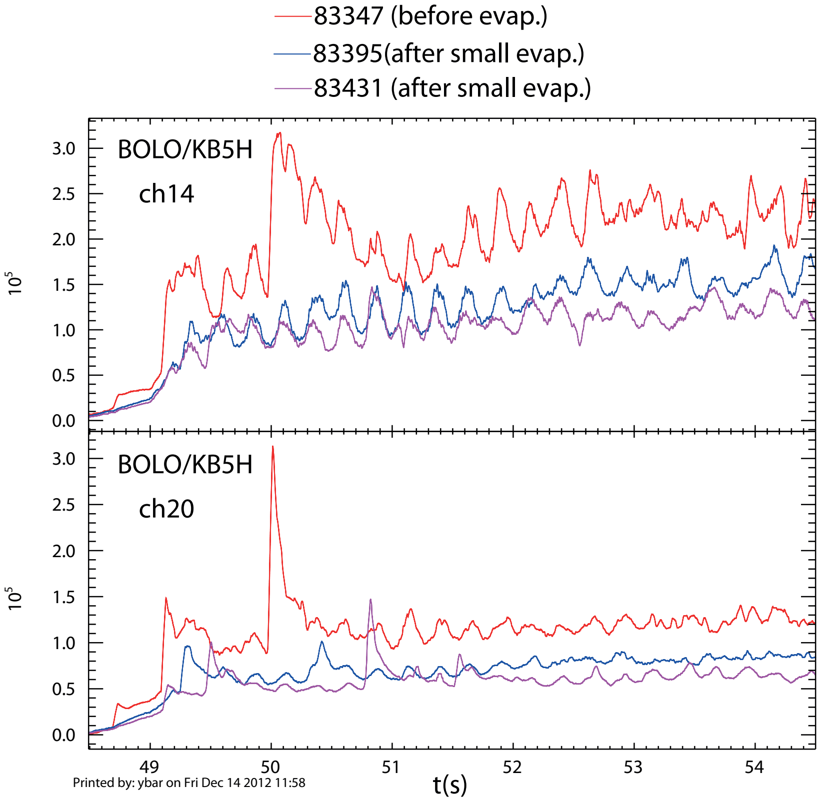
* see for details: “Confinement and W accumulation in hybrid pulses”
http://users.jet.efda.org/pages/tfe1e2/TF_E1E2_Meetings/2012/29May12/Baranov_290512.ppt

Effect of Be evaporation on radiation

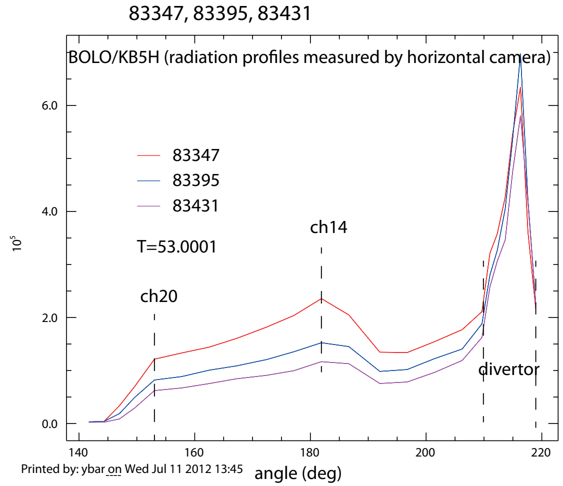


Effect of Be evaporation on radiation

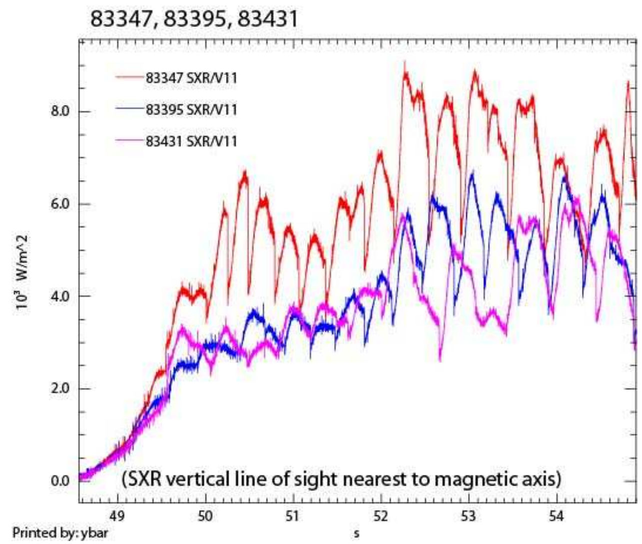
Be evaporation reduces core radiation -> reduces tungsten content



Effect of radiation event (83347 at 50s) does not affect general tendency as it disappears after ~1s



bolometer



SXR