ASDEX Upgrade hybrid regime: requests in terms of modelling

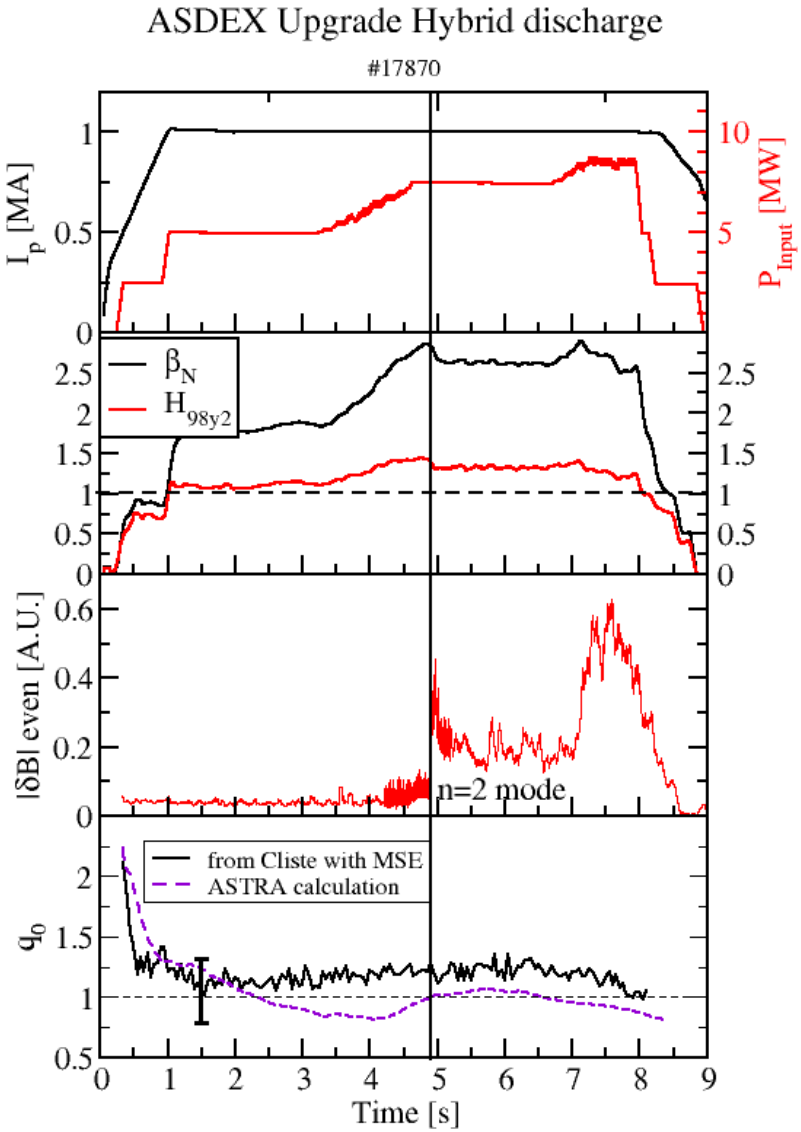
Jörg Hobirk, J. Schweinzer, J. Stober

ISM meeting, Lisbon 2010

Outline

- Improved H-mode in ASDEX Upgrade (hybrid)
- Challenges for modelling:
  - Non classical current profile
  - Confinement improvement mostly in pedestal
  - NBCD does not work as expected
  - Impurity transport/influence on transport
- Three pulses can be provided for code validation
- Nowadays most difficulties in understanding are related to impurities → for the time being no further modelling needs

An example of a ASDEX Upgrade improved H-mode

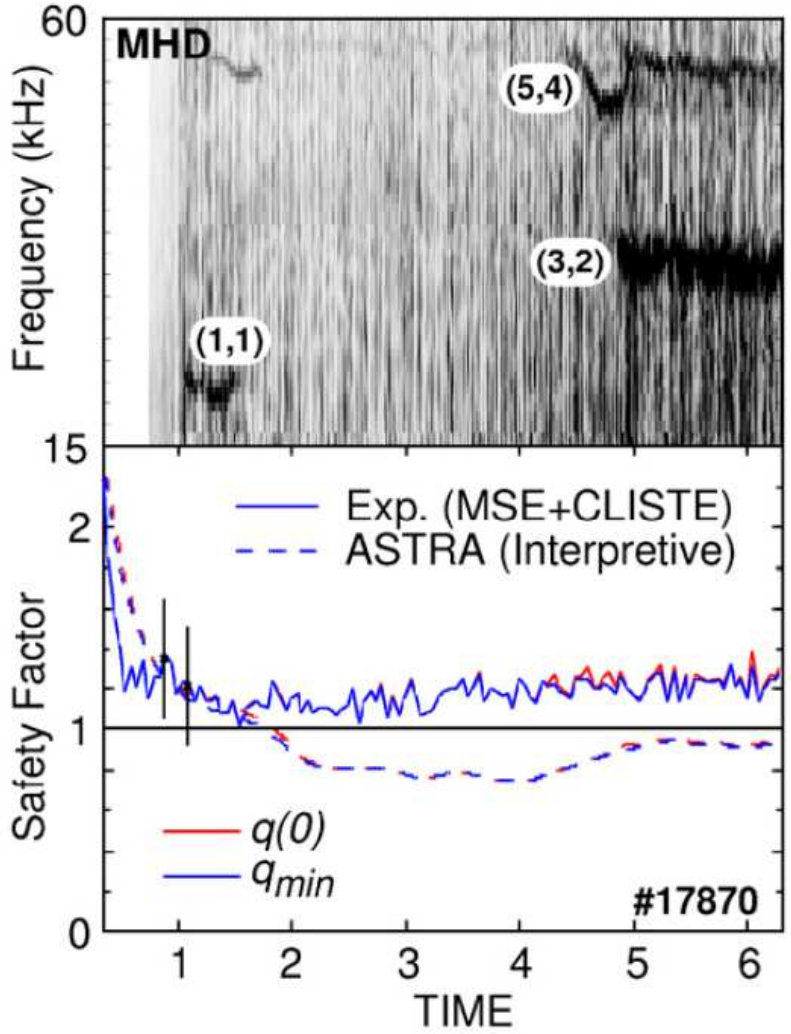


- Target q_0 after current ramp between 1 and 1.5
- Low power NBI phase for slow relaxation of *q*-profile without significant MHD
- High power NBI phase to reach target beta
- q_0 stationary above 1, backed up by non 1/1 MHD activity in plasma
- Confinement significantly enhanced without ITB
- Current diffusion not explained in classical picture

Y.S. Na *et al*, Nucl. Fusion 46 (2006) 232–243

Differences in current diffusion to clasical picture not explained by MHD

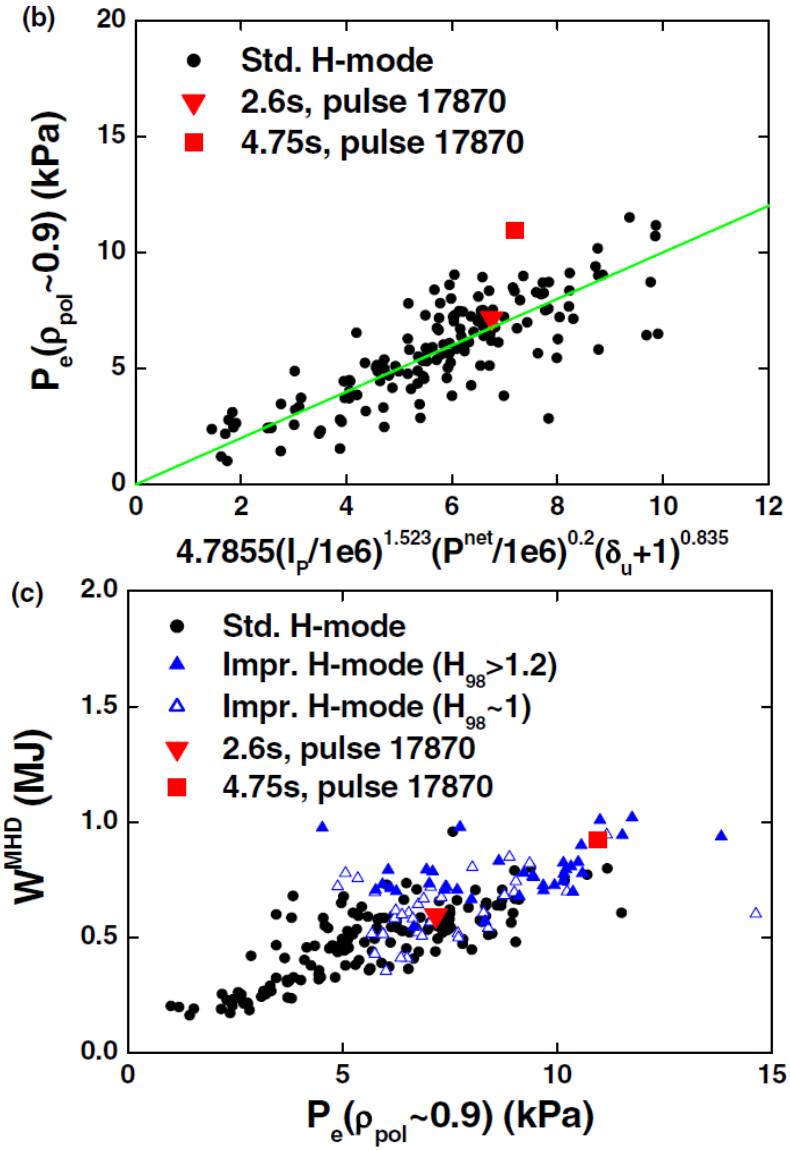
- Only 1/1 activity visible
- For a short time
- Main discrepancy is produced later



Y.S. Na *et al*, Nucl. Fusion 46 (2006) 232–243

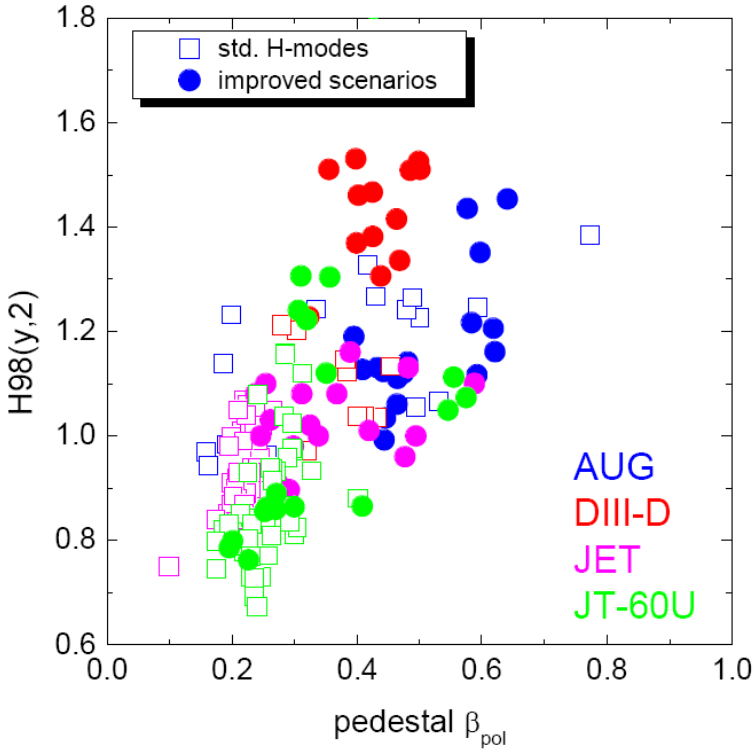
Confinement improvement dominated by pedestal

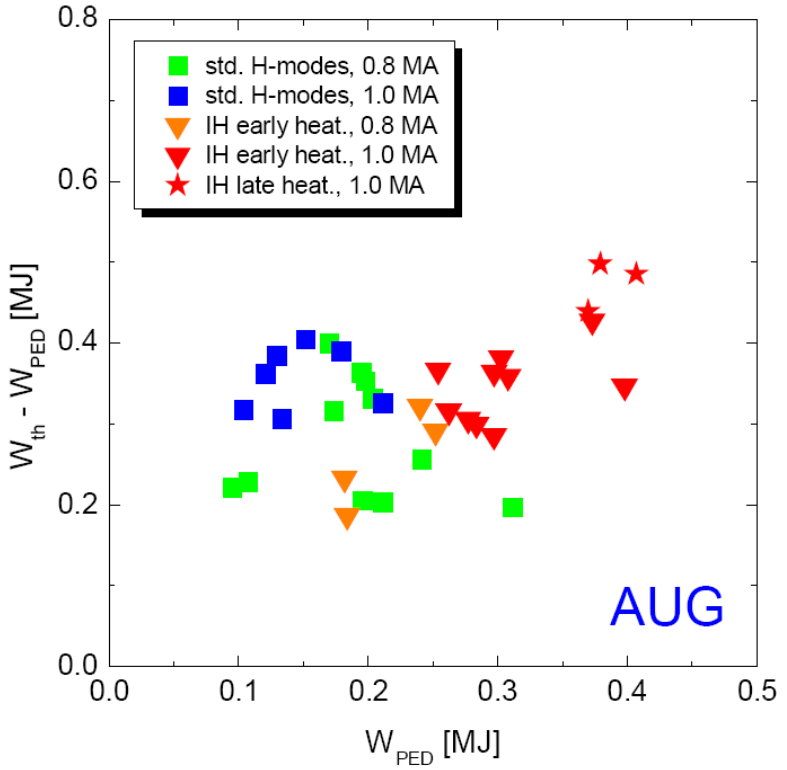
- Low power phase similar to H-mode
- High power phase has improved pedestal pressure
- Global confinement scales linearly with pedestal pressure
- Analysis in paper resticted to electrons because of missing diagnostic



Y.S. Na *et al*, Nucl. Fusion 46 (2006) 232–243

In most cases the confinement is pedestal dominated





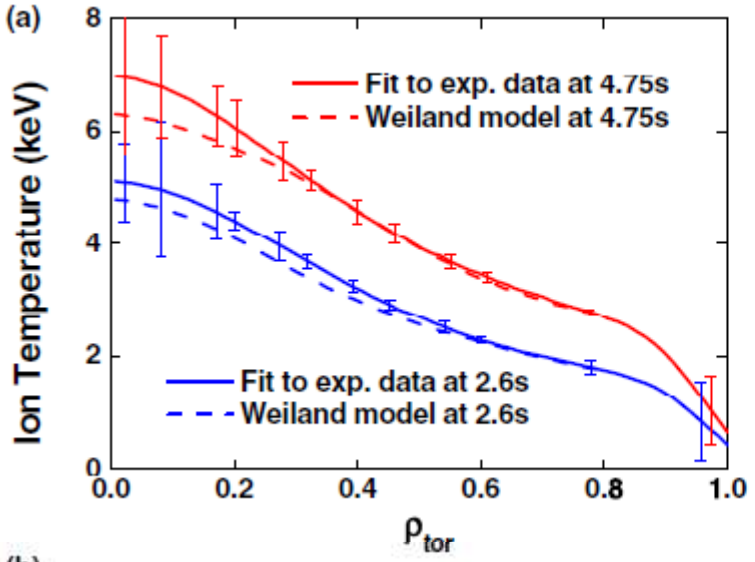
Differences in H_{98} dominated by pedestal pressure

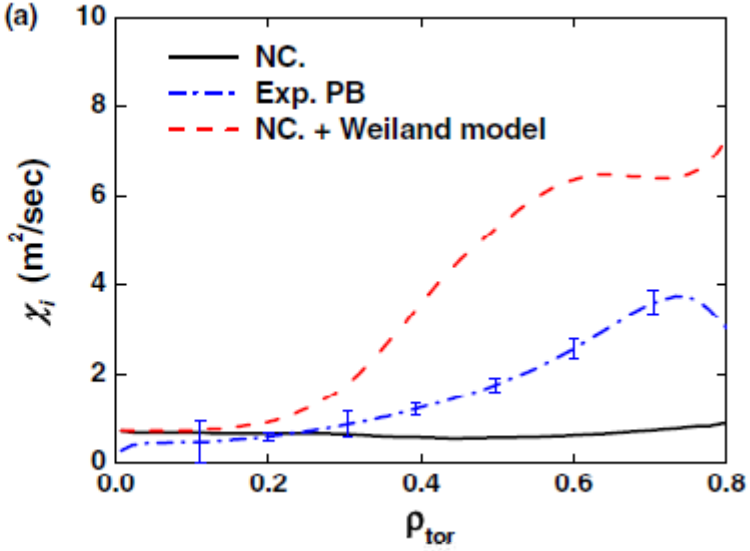
- Confinement increases with pedestal pressure
- W_{ped}/W_{core}≈const.

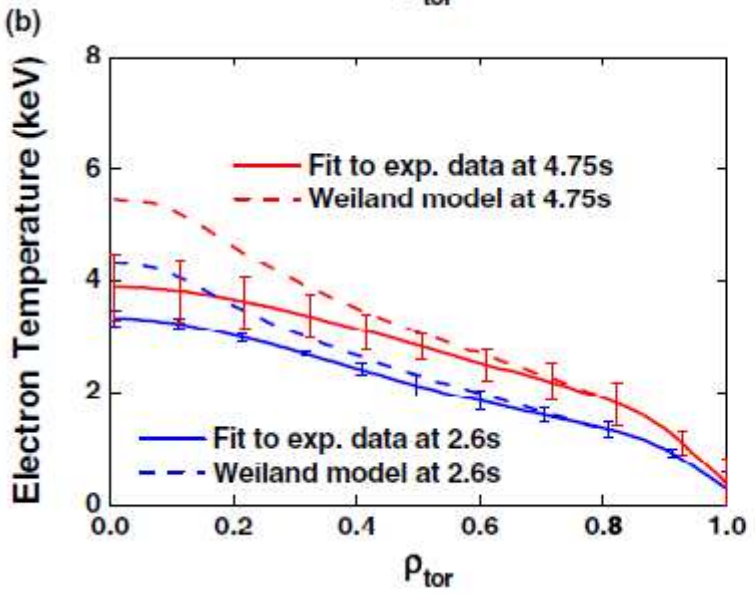
C. Maggi et al. Nucl. Fusion, Vol. 47, 2007

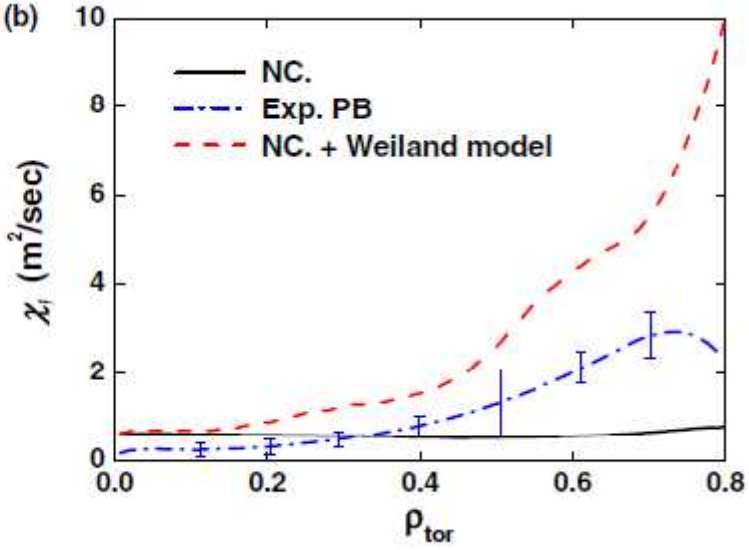
Ion transport consistent with Weiland model

- Ion transport consistent with Weiland model
- Electron transport underestimated by Weiland model





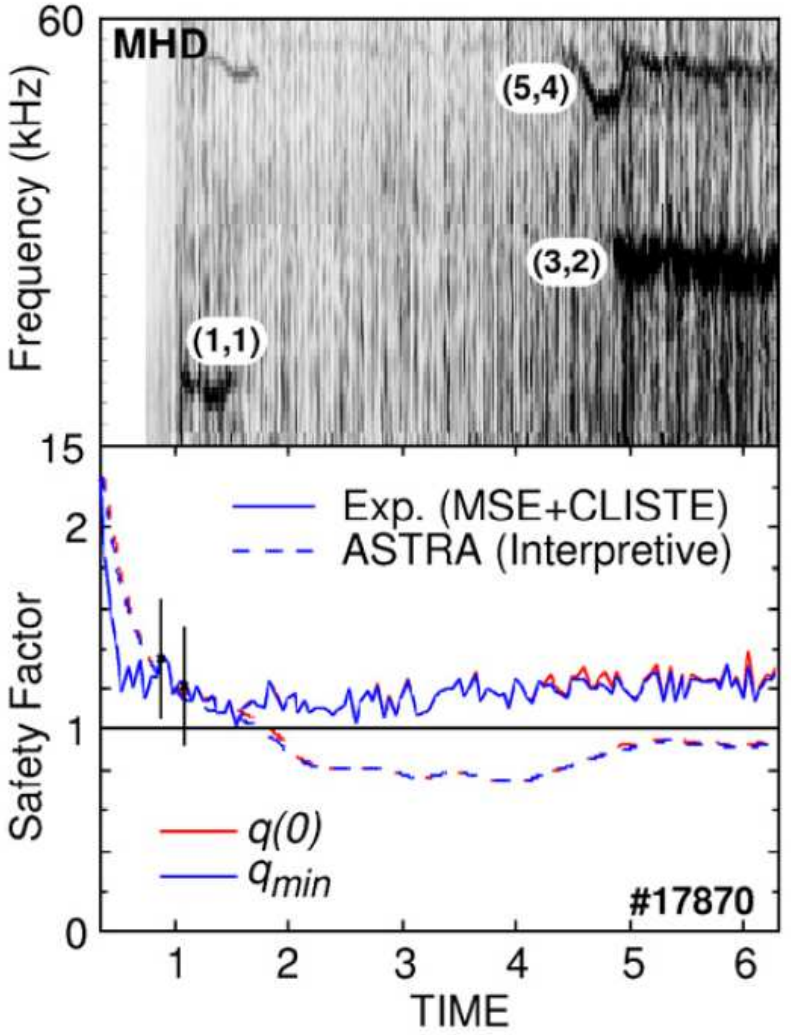




Y.S. Na *et al*, Nucl. Fusion 46 (2006) 232–243

Differences in current diffusion to clasical picture not explained by MHD

- Only 1/1 activity visible
- For a short time
- Main discrepancy is produced later
- Especially increase in q0 at t=4s not seen in Experiment
- → NBCD anormality
  - Case 1: high triangularity 5MW
  - Case 2: low triangularity 5MW



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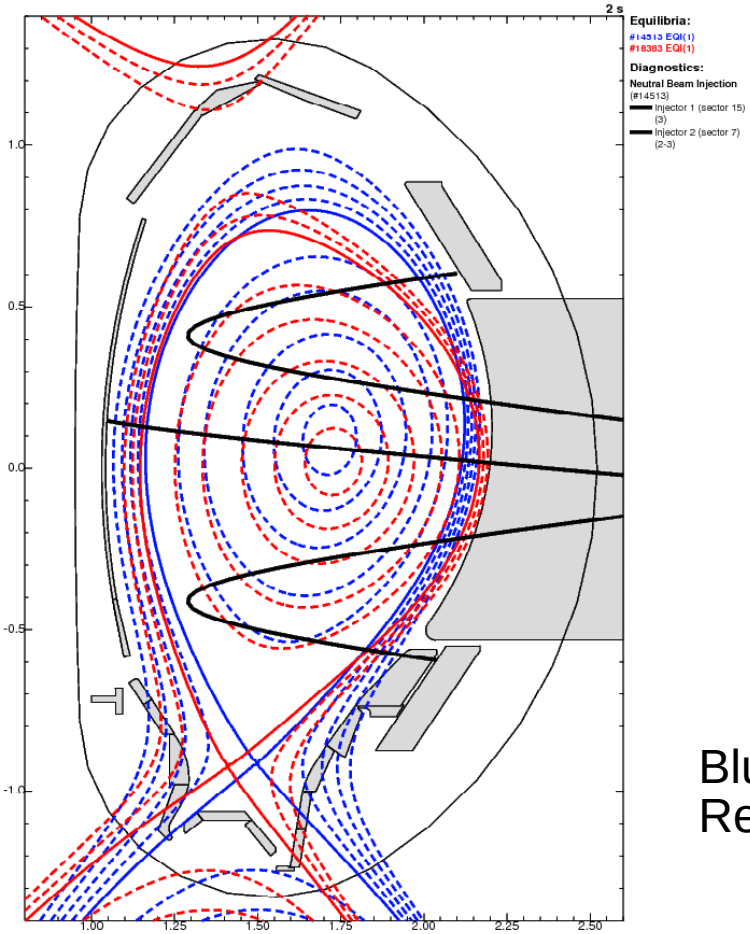
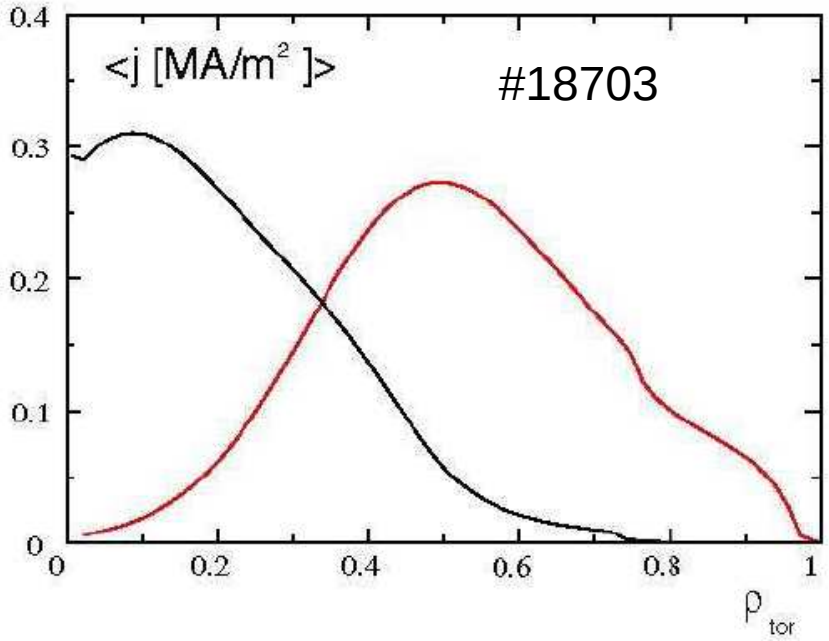
Poloidal geometry and expected NBCD profiles

Our beams very tangential, trapping effect most pronounced for injection below magnetic axis, nearly no effect for symmetric injection

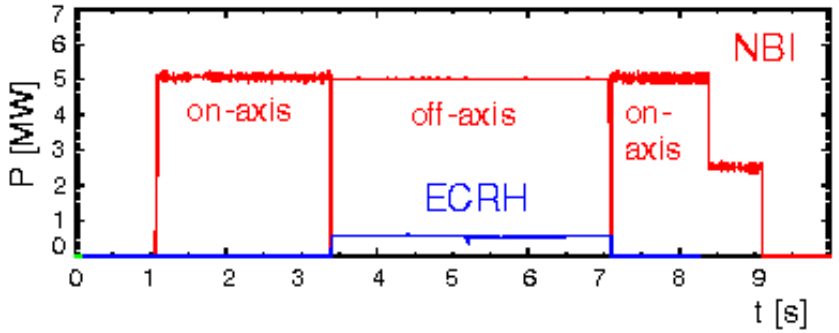


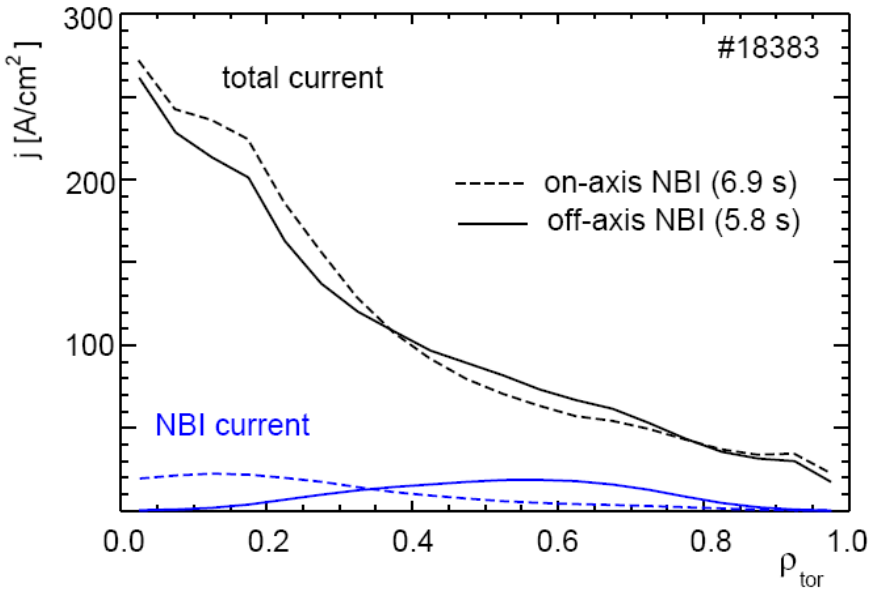


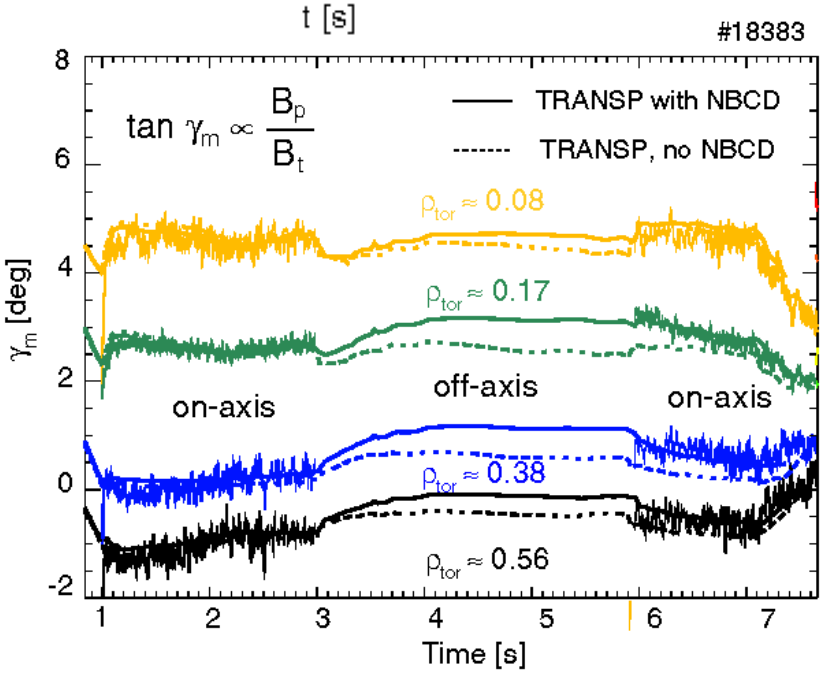
Blue: low triangularity
Red : high triangularity

S. Günter *et al*, Nucl. Fusion 47 (2007) 920–928

Off-axis current drive experiments on ASDEX Upgrade high triangularity



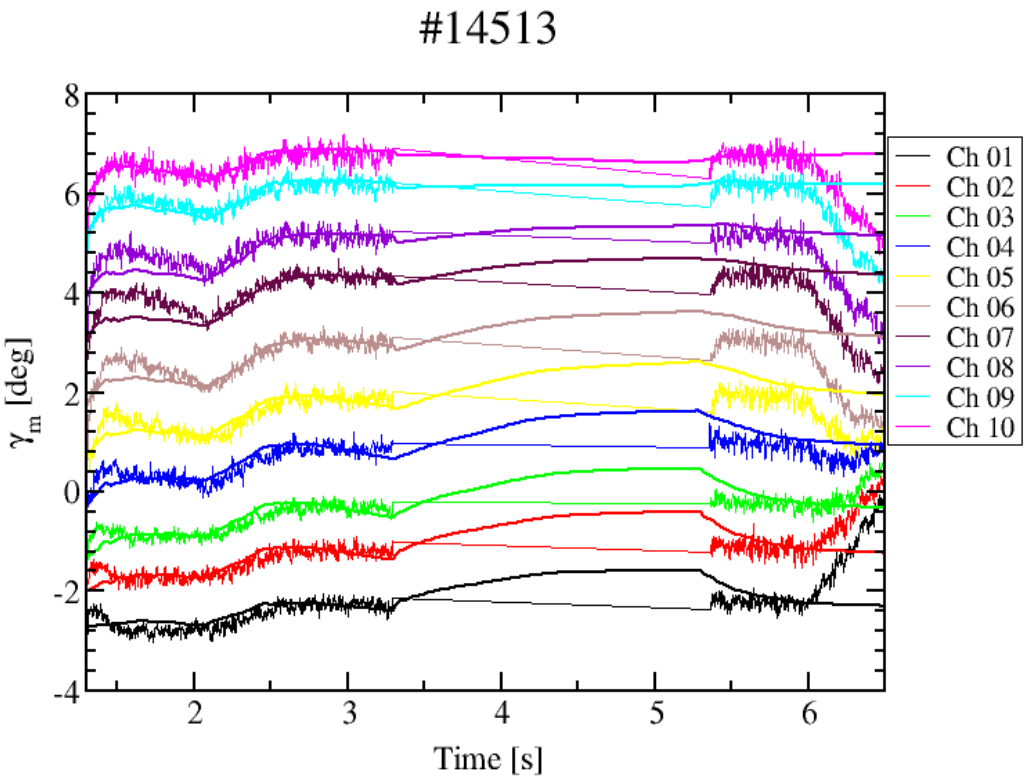


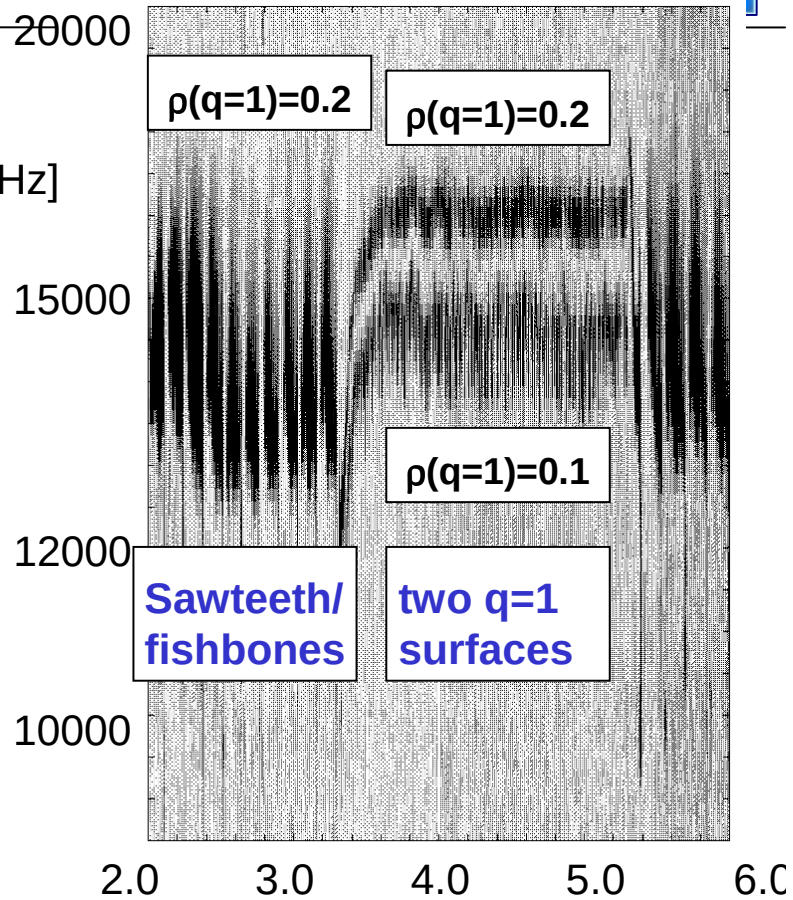


Driven current follows the expectations from code calculations

S. Günter *et al*, Nucl. Fusion 47 (2007) 920–928

But no effect on MSE angles or q=1 position

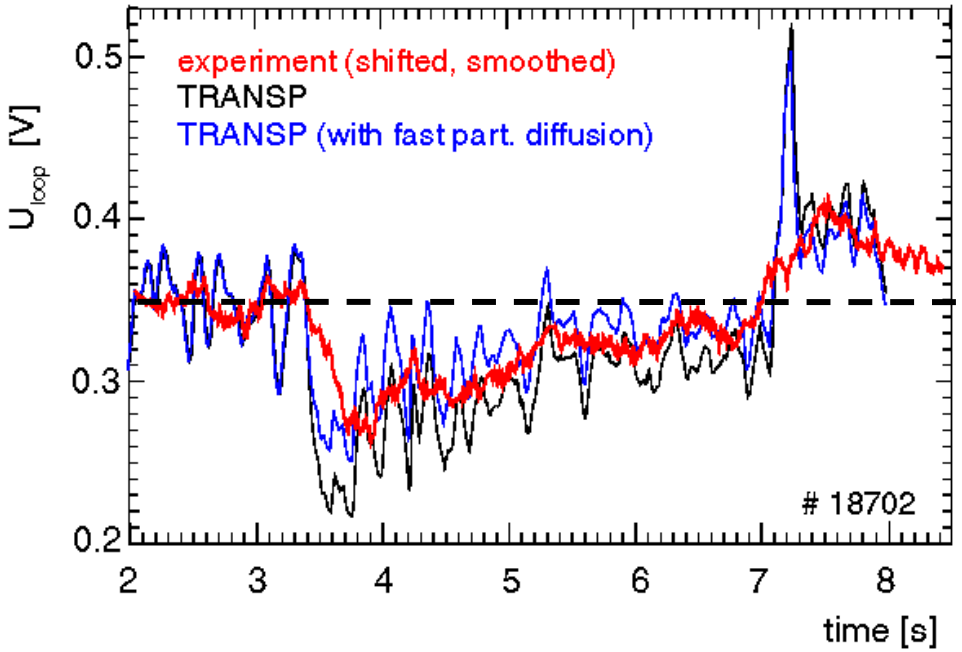


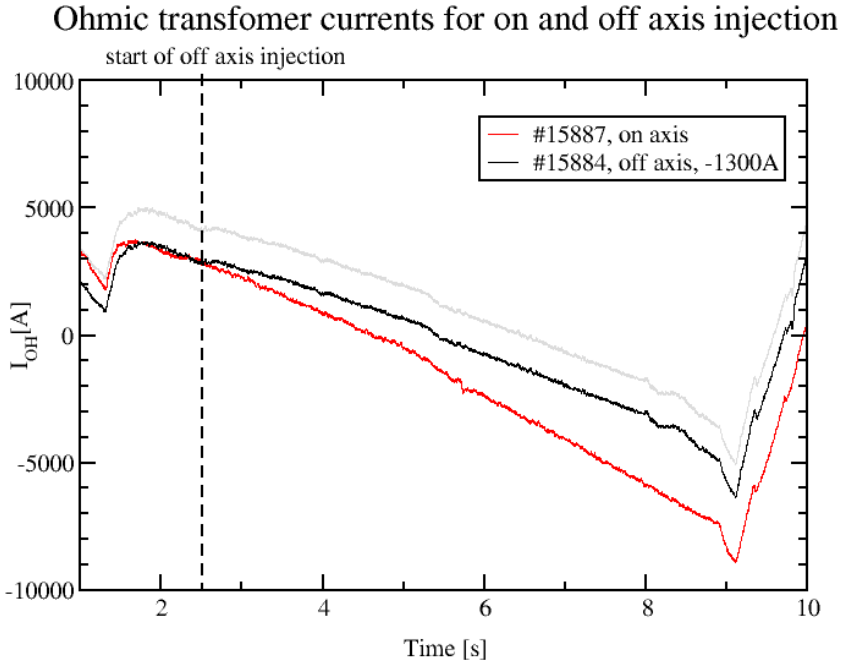


- MSE angles do not follow the expectations
- Within measurement accuracy no off-axis current driven
- MHD in fully consistent with no change of q inside ρ=0.2
- No FP modes observed

J. Hobirk *et al*, EPS 2003

Total current drive efficiency as predicted by theory

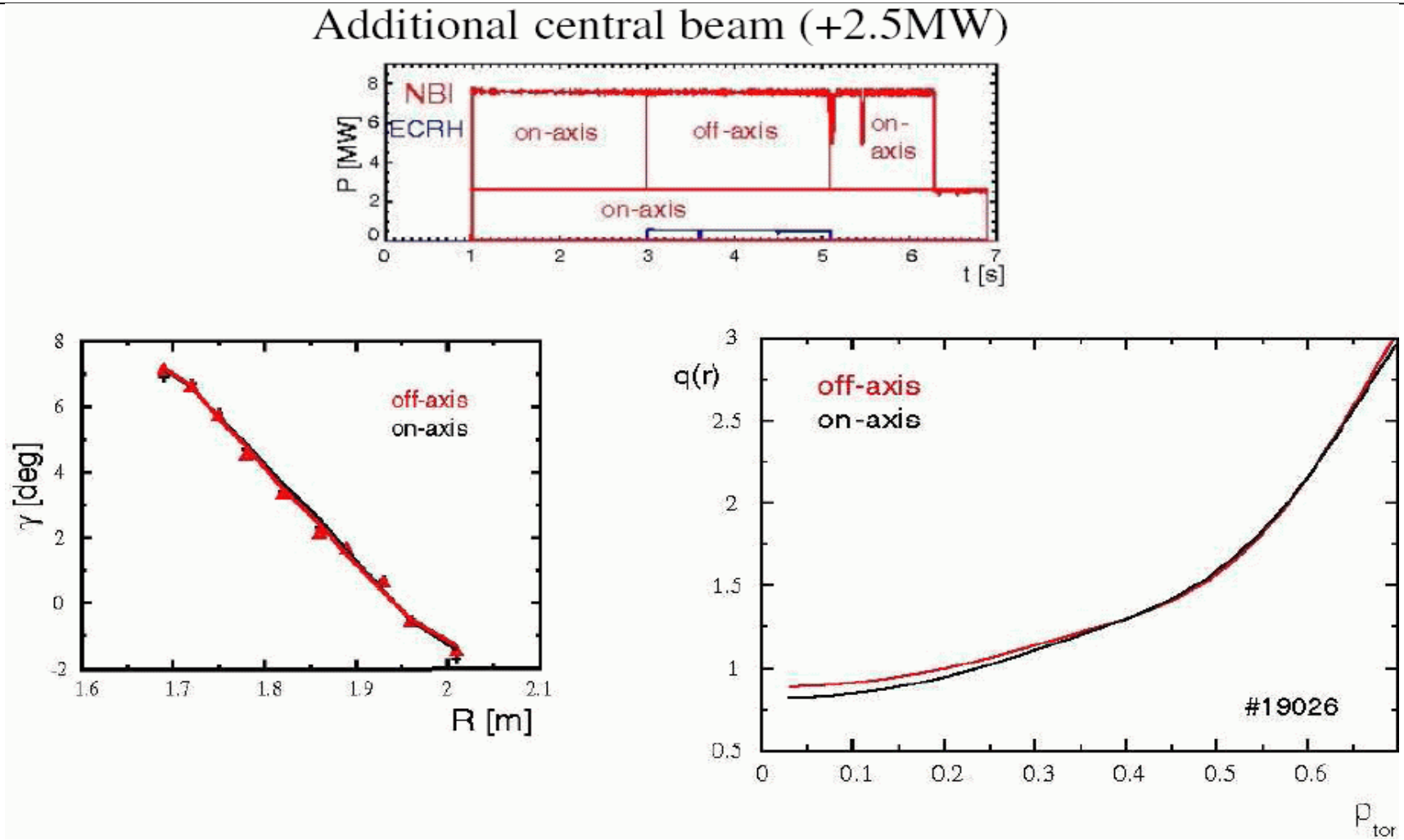




- Off-axis NBI drives more current because of a more tangential injection
- Visible change in loop voltage and OH consumption
- Within measurement accuracy consistent with code calculations

S. Günter *et al*, Nucl. Fusion 47 (2007) 920–928

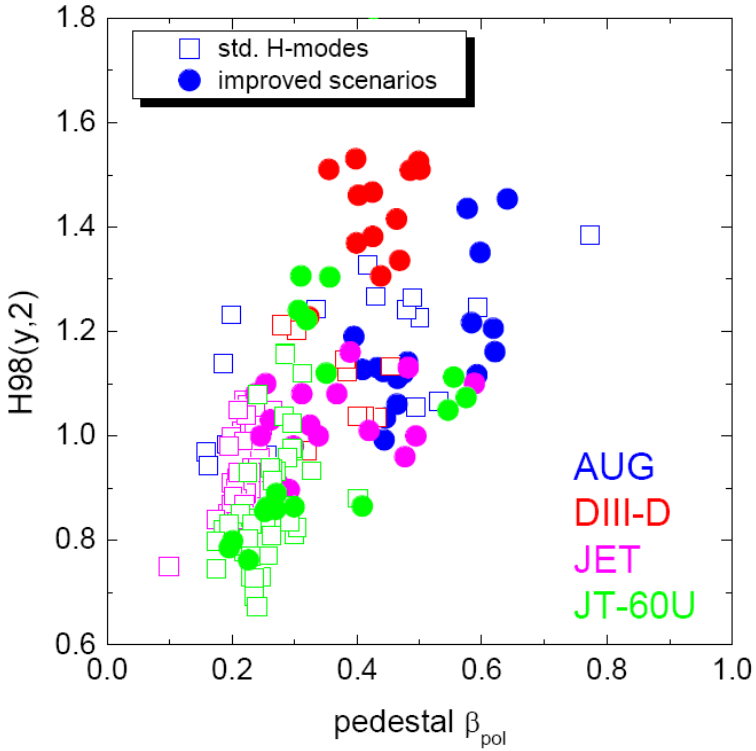
In high triangularity current profile effect vanishes with 7.5MW

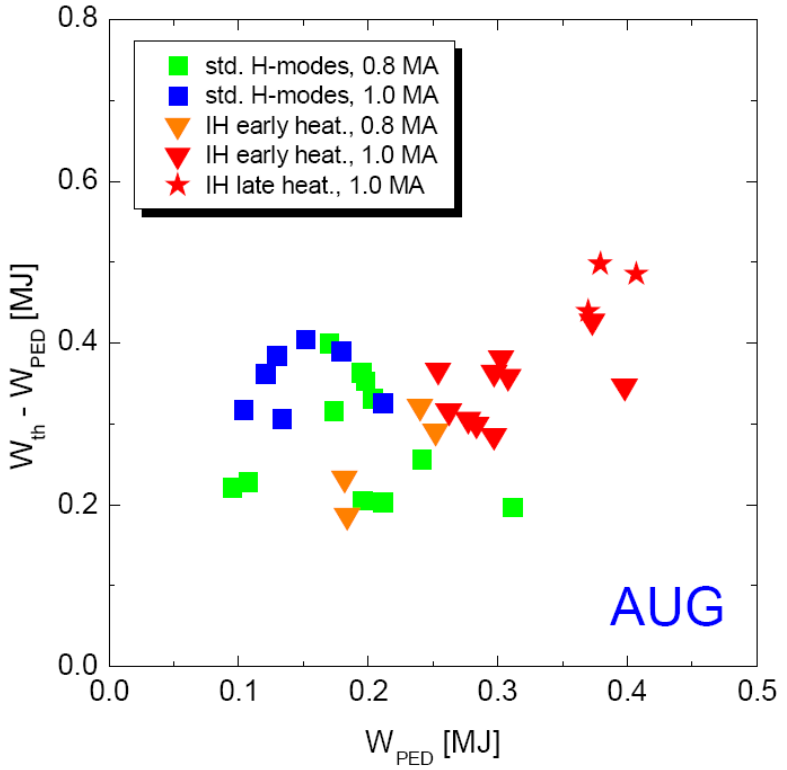


- With 2.5MW central heating more no effect of NBCD visible

S. Günter *et al*, Nucl. Fusion 47 (2007) 920–928

In most cases the confinement is pedestal dominated





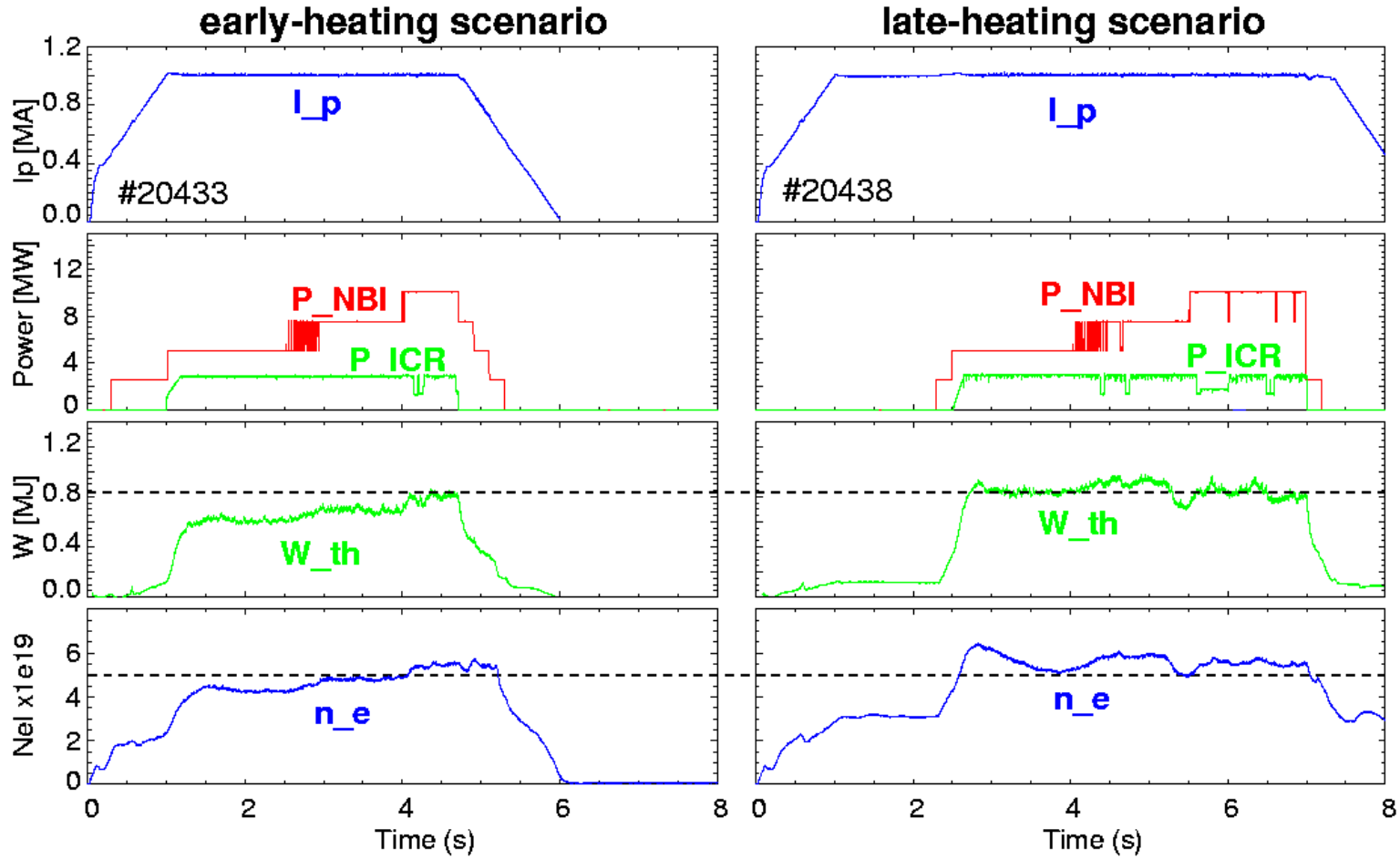
Differences in H_{98} dominated by pedestal pressure

- Confinement increases with pedestal pressure
- W_{ped}/W_{core}≈const.

  → *But late heating might be different*

C. Maggi et al. Nucl. Fusion, Vol. 47, 2007

Motivation : Importance of ramp-up scenario



Ramp-up scenario can influence confinement significantly !

J. Stober *et al*, Nucl. Fusion 47 (2007) 728–737

Systematic study

#	Te0 (1.0 s)	$\langle ne \rangle$ (1.0 s)	PNBI (preheat)	q0	q95	$H98_{y,2}$	MHD behaviour during high power phase
	[keV]	1E19m^3	[MW]				
20998	3.0	2.5	2.5	2.0	4.0	-	Disrupts after ITB
20993	3.4	2.2	2.5	3.2	4.8	1.2	4/3 NTM, 3/2 NTM at 3.2s
20991	2.6	3.6	2.5	2.8	4.8	1.2	4/3 NTM, 3/2 NTM at 2.3s
20990	2.2	5.5	2.5	2.2	4.8	1.2	4/3 NTM, 3/2 NTM at 1.8s
20992	1.5	5.3	1.25	?	4.8	1.2	4/3 NTM throughout
20994	1.6	2.9	0	1.0	4.8	-	Fishbones, wall contact
20995	1.6	2.9	0	0.95	4.8	1.5	Fishbones throughout
20996	1.1	2.9	0	0.8	4.0	1.5	Fishbones
20997	1.1	2.9	0	0.8	4.0	1.5	4/3 NTM $\rightarrow$ Fishbones
20999	1.0	5.2	1.25	?	4.0	1.2	4/3 NTM throughout

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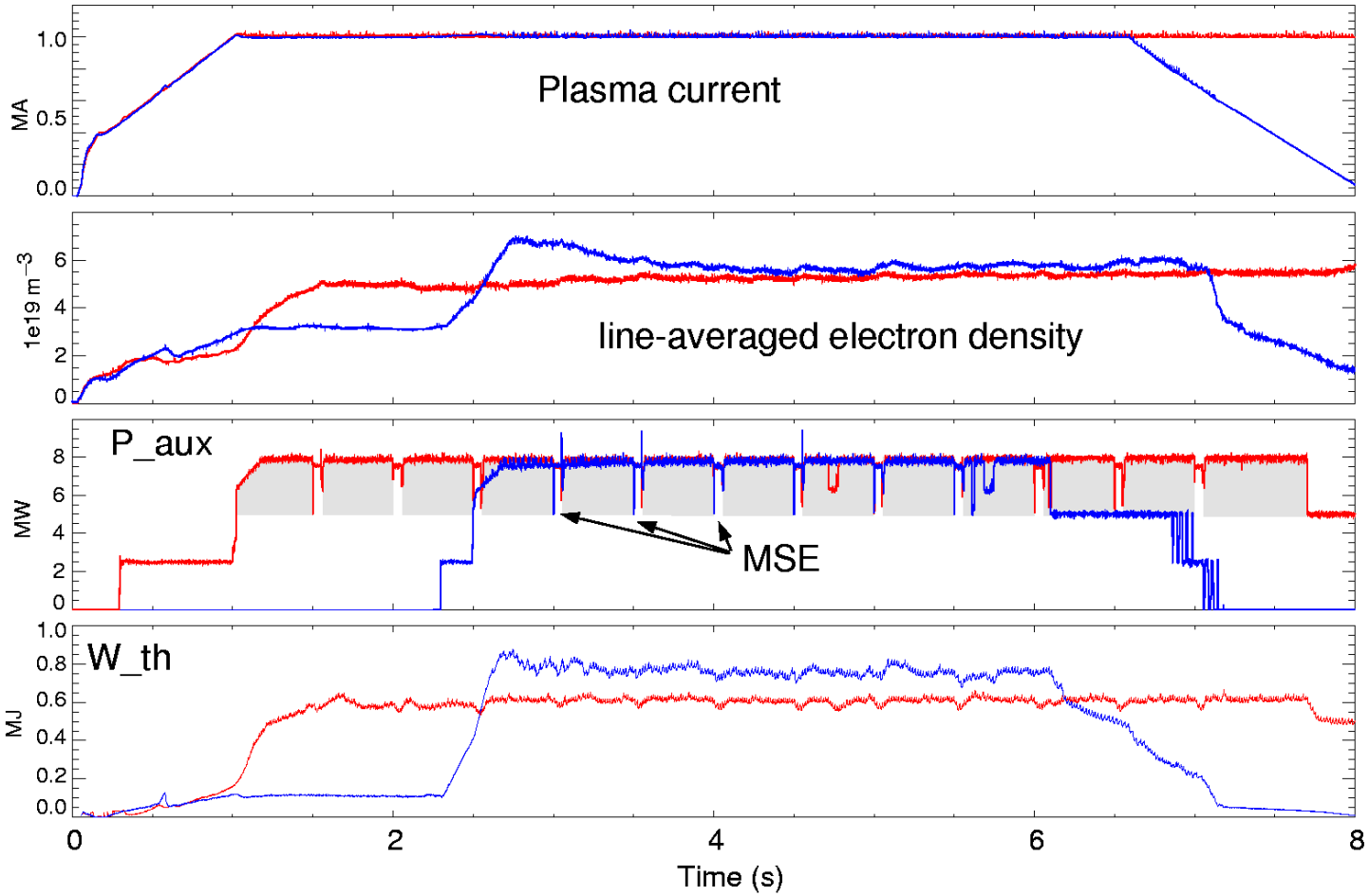
Early and late heating



#20993
#20995

Confinement significantly better with late heating scheme

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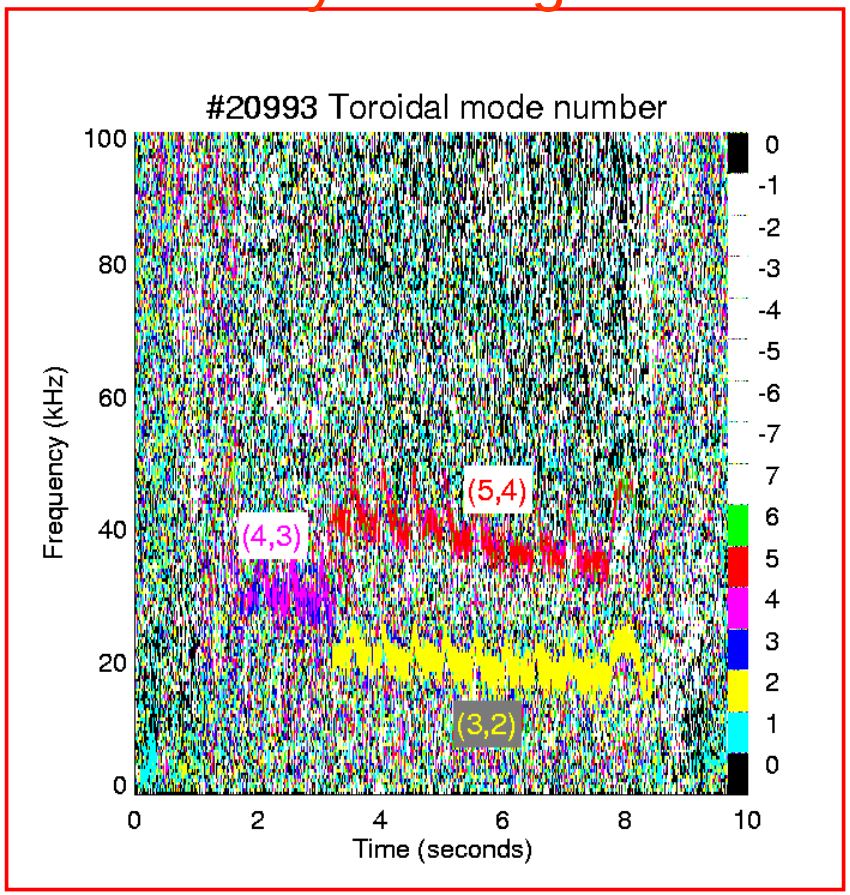
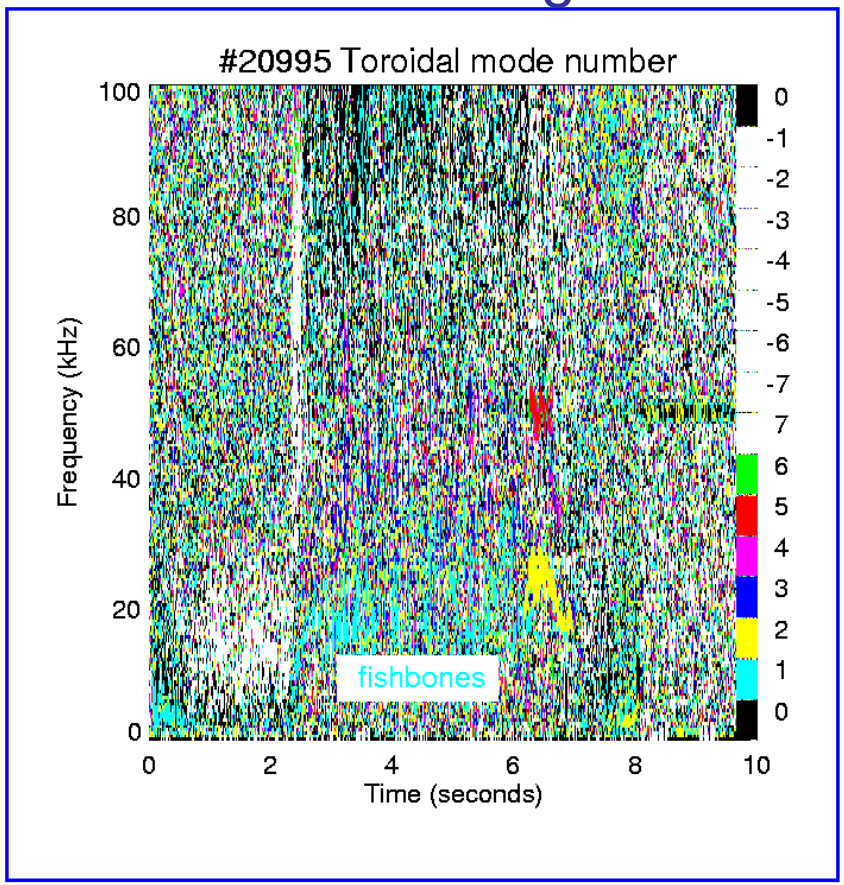
MHD significantly different

early heating

late heating





(4,3) and (3,2) NTMs

fishbones

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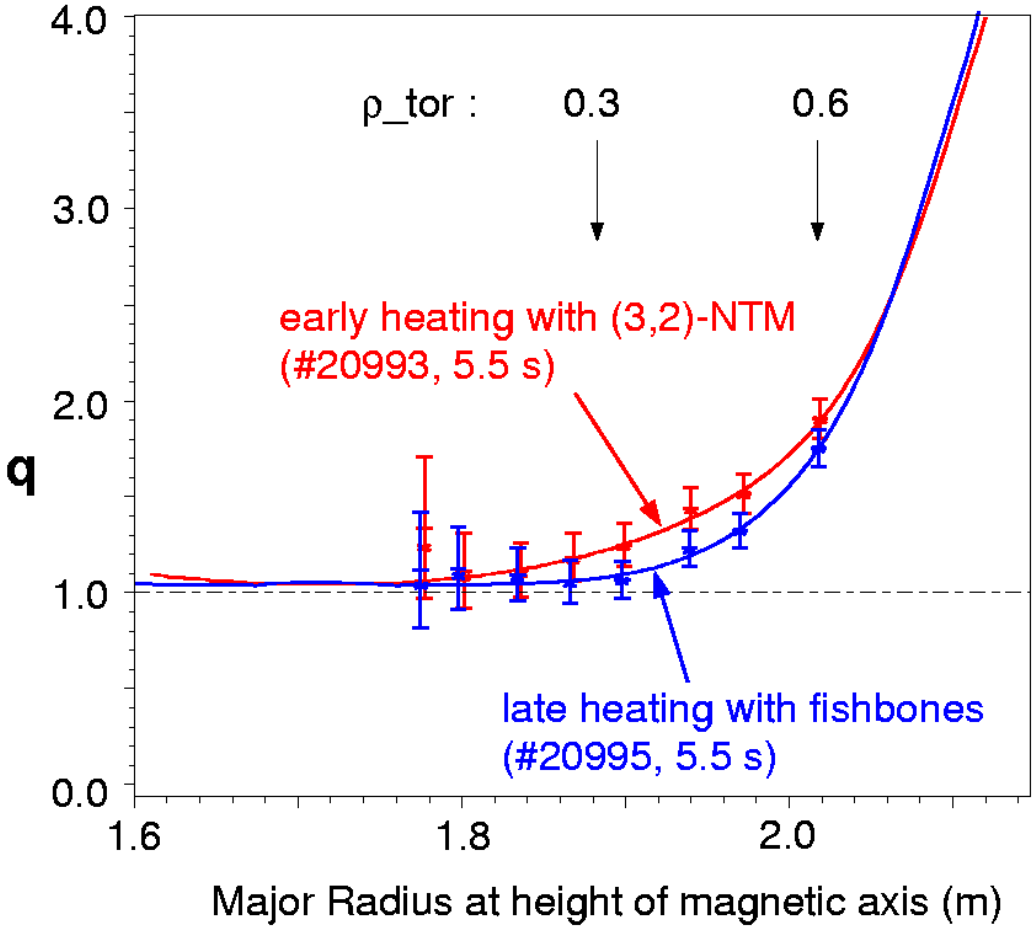
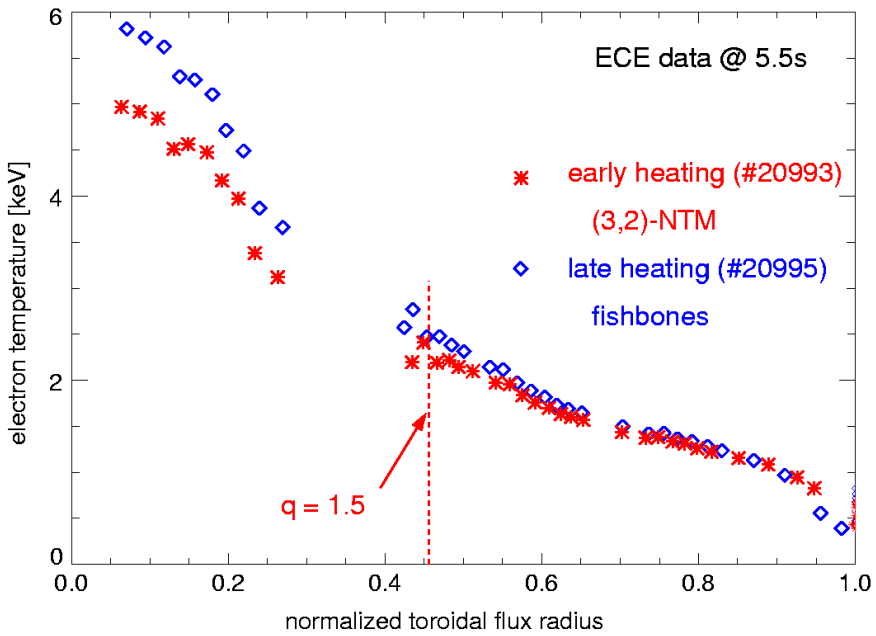
q-profiles: difference significant for $0.3 < \rho_t < 0.6$

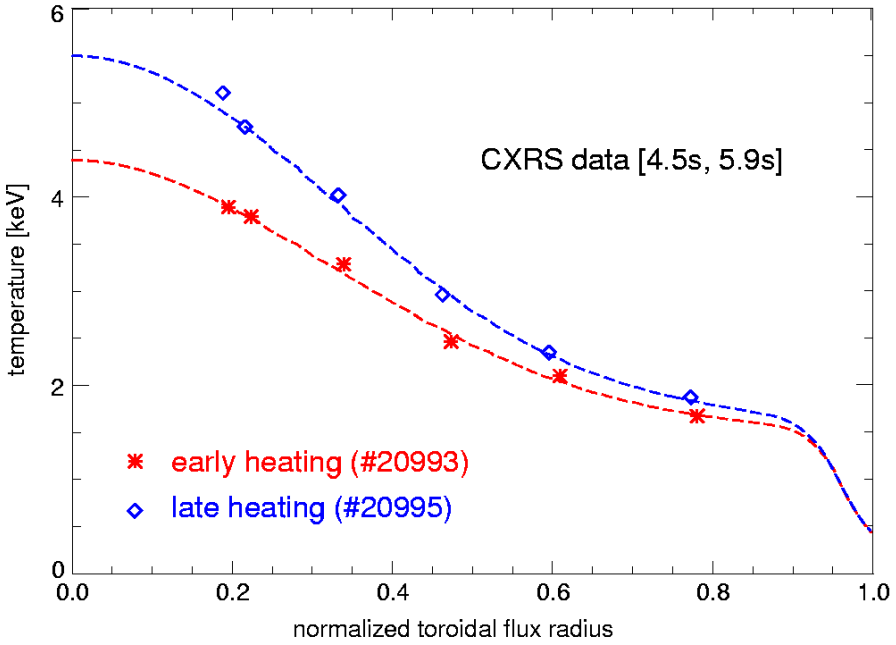


Do changes in q-profile and MHD explain changes in n,T profiles?

J. Stober *et al*, Nucl. Fusion 47 (2007) 728–737

Differences in kinetic data : T_e





T_e shows expected effect of (3,2)-NTM-island

T_i profile varies over wide radial range, as does L_{Ti}

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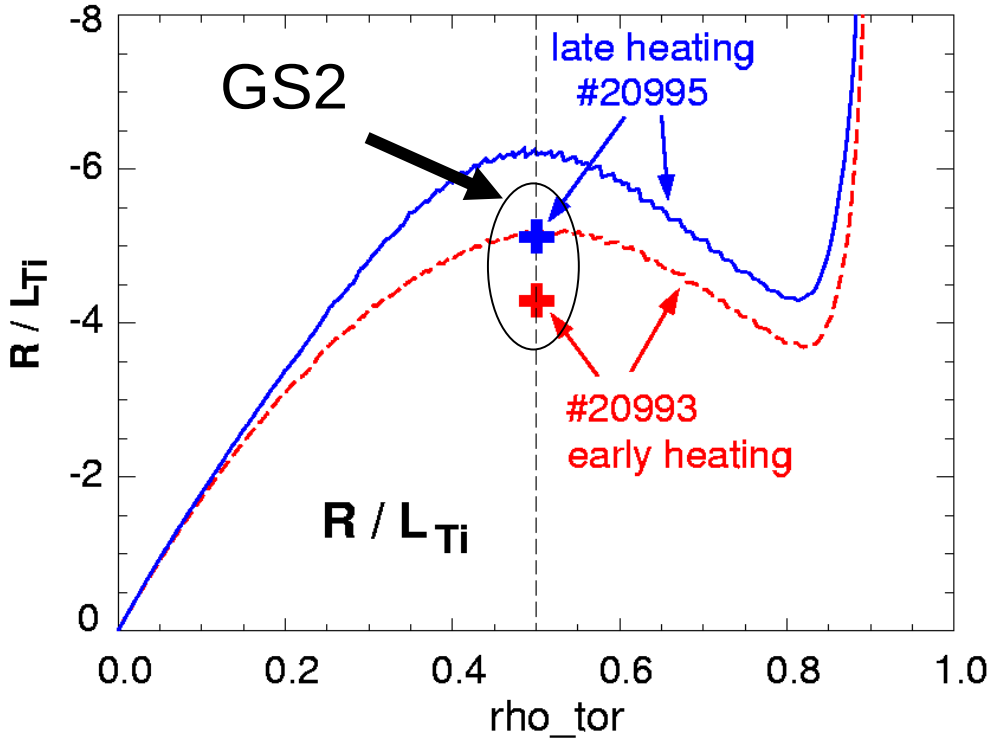
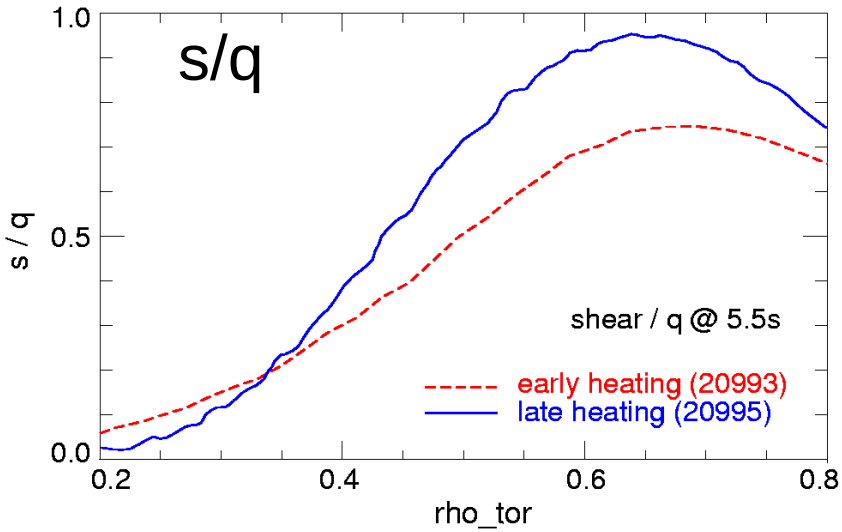
Variation of L_{Ti} consistent with variation of s/q





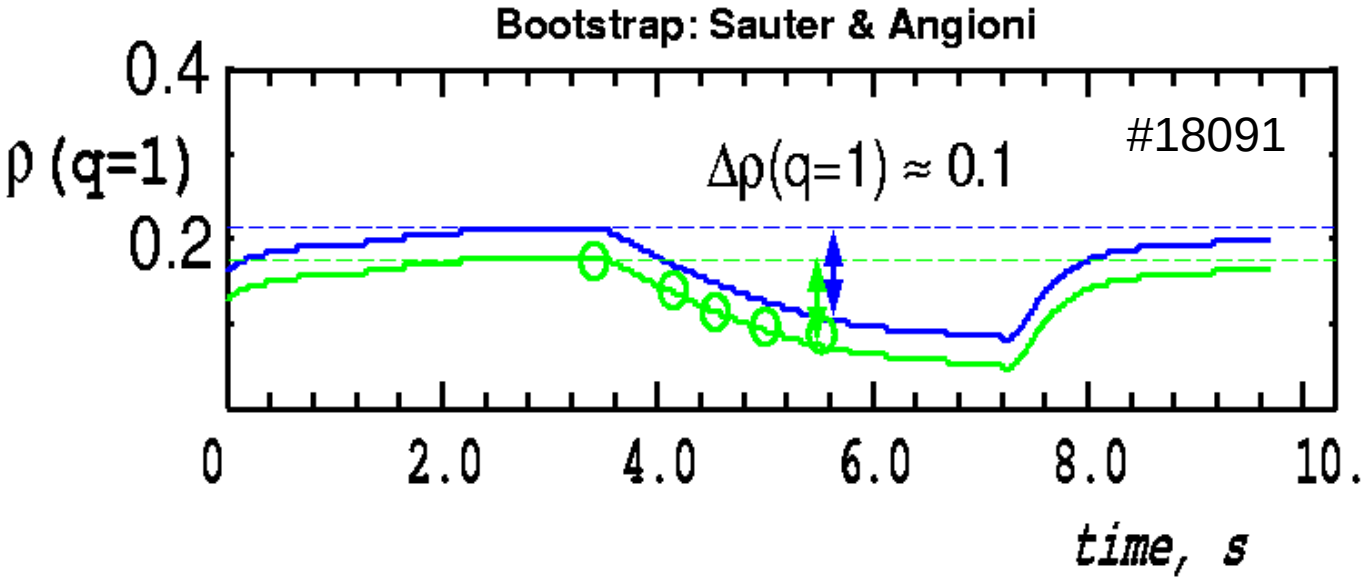
Based on GS2-calculations only varying s/q
n, T, v_{tor} from late heating discharge

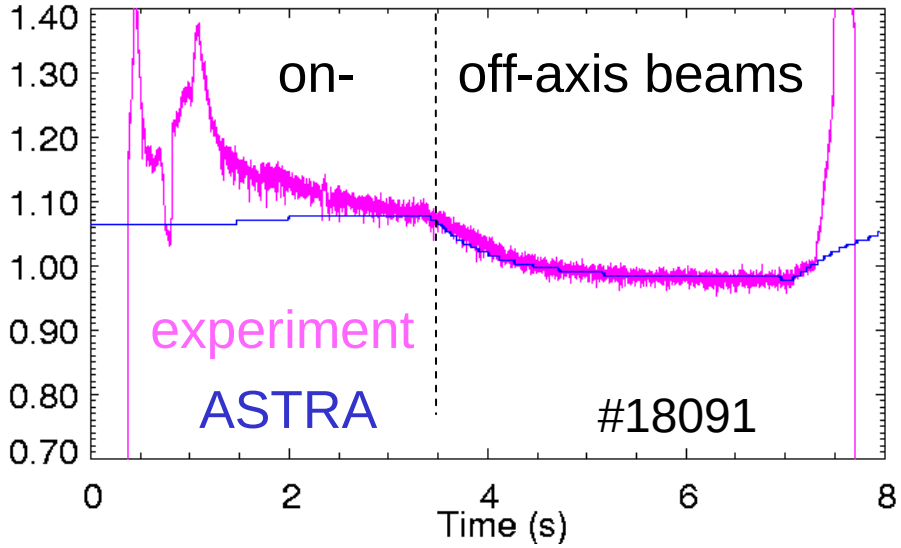
J. Stober *et al*, Nucl. Fusion 47 (2007) 728–737

Summary

- 3 pulses (#17870,#20993,#20995) can be supplied to ISM
- Challenges
  - in terms of current distribuion,
  - confinement enhancement and
  - non classical NBCD
- are waiting
- For the time being AUG has no further modelling needs

Strong change in l_i and q=1 for 1 source

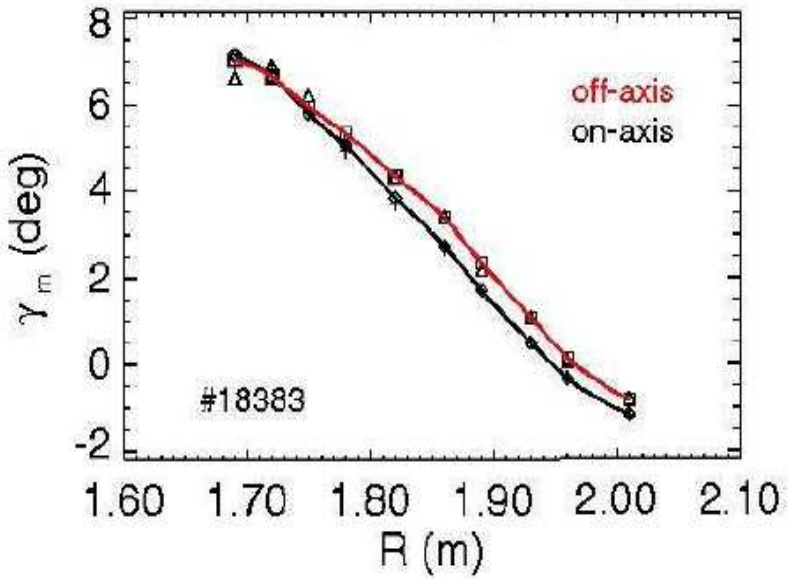


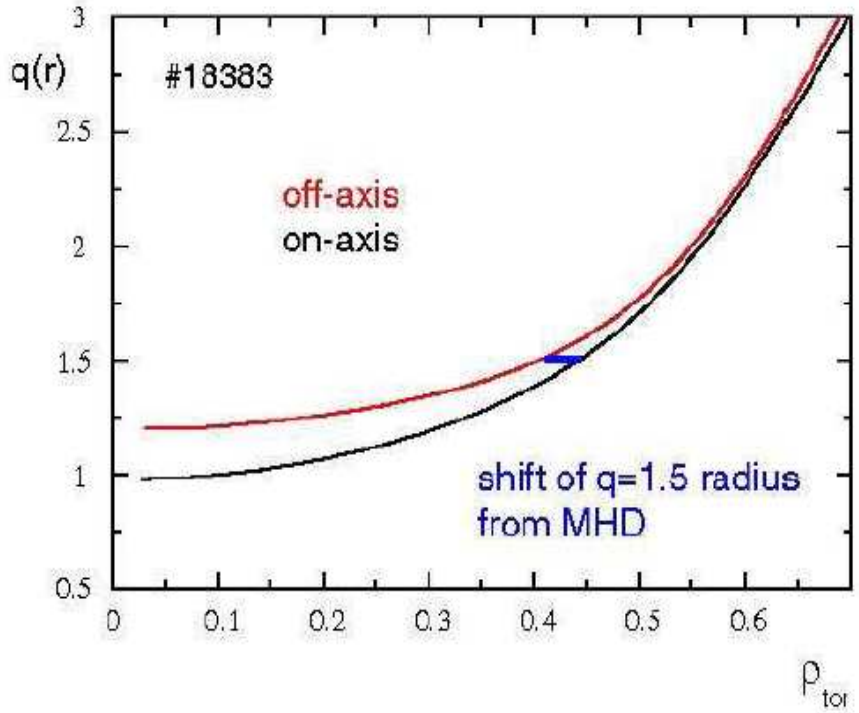


one-beam discharge

Change in l_i and movement of q=1
for one-beam case
in agreement with ASTRA code

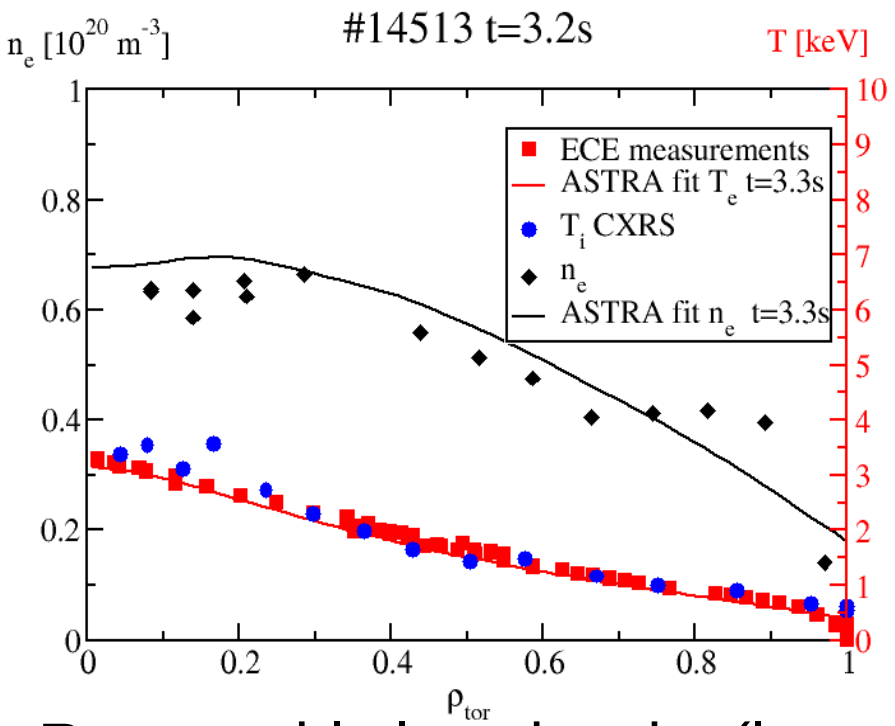
Whole profile changes

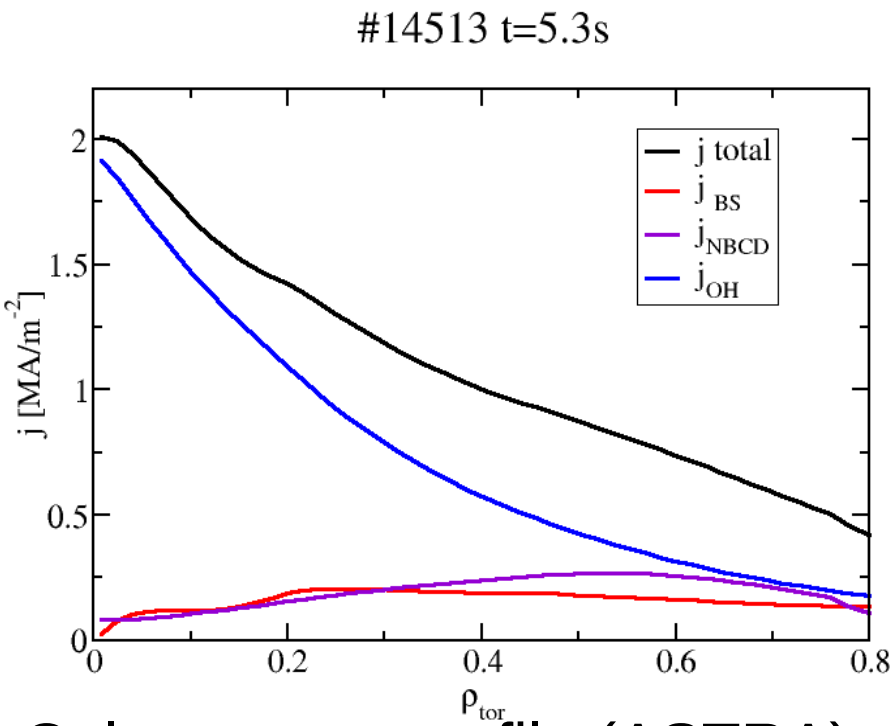




- Effect clearly visible on MSE angles
- Also reflected in q-profile change

In low triangularity a change in q should be measurable

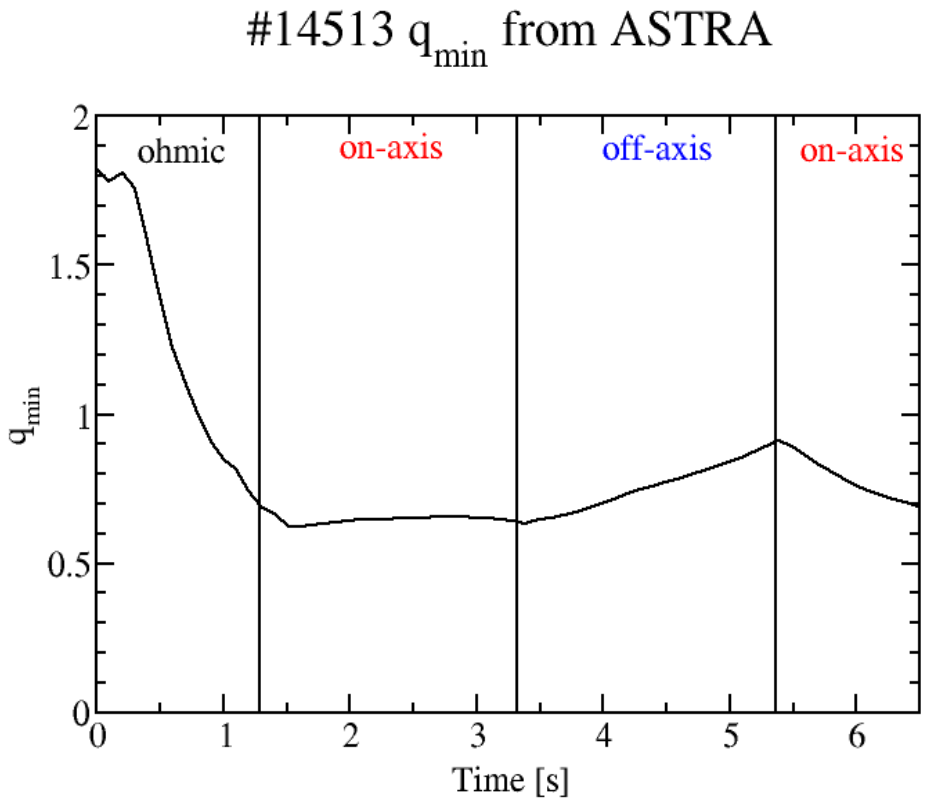


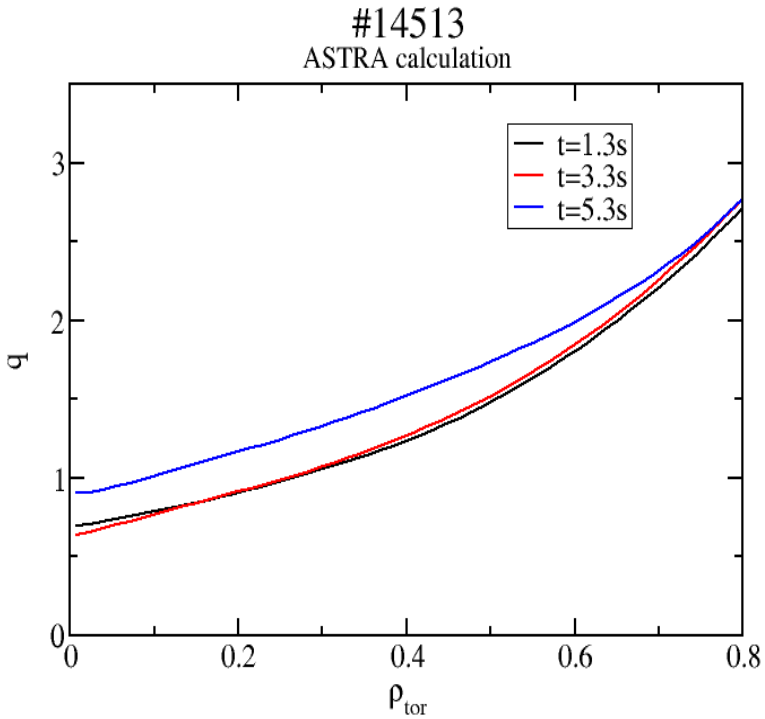


- Reasonably low density (lower than high triangularity)
- Medium temperature (risk of NTMs)
- Medium current drive

- Calc. current profile (ASTRA)
- Beam current significant
- Boot strap current not negligible
- I_{NBCD}=192kA at t=5.3s
- I_{NBCD}=61kA at t=3.3s on axis

In low triangularity a change in q should be measurable

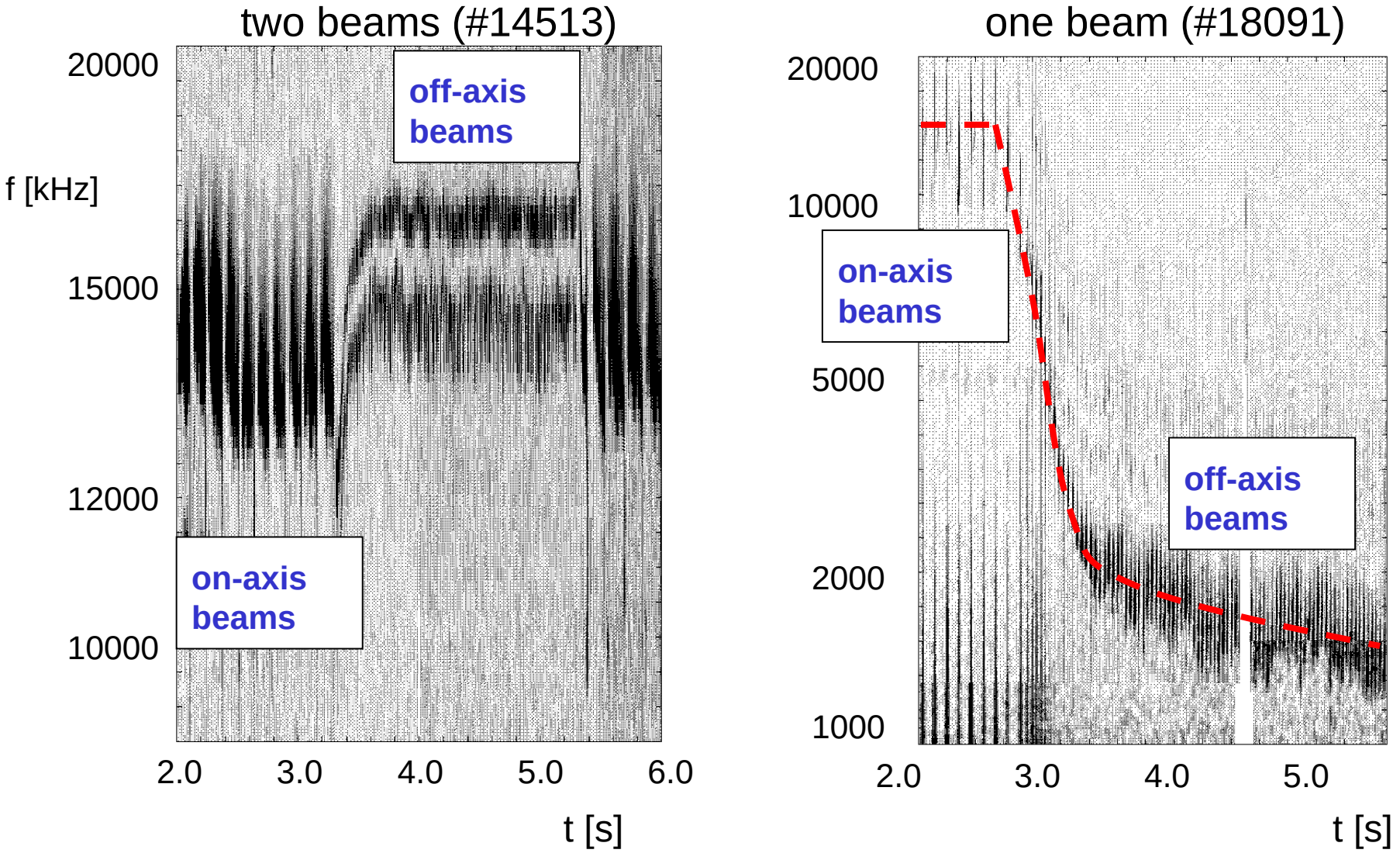




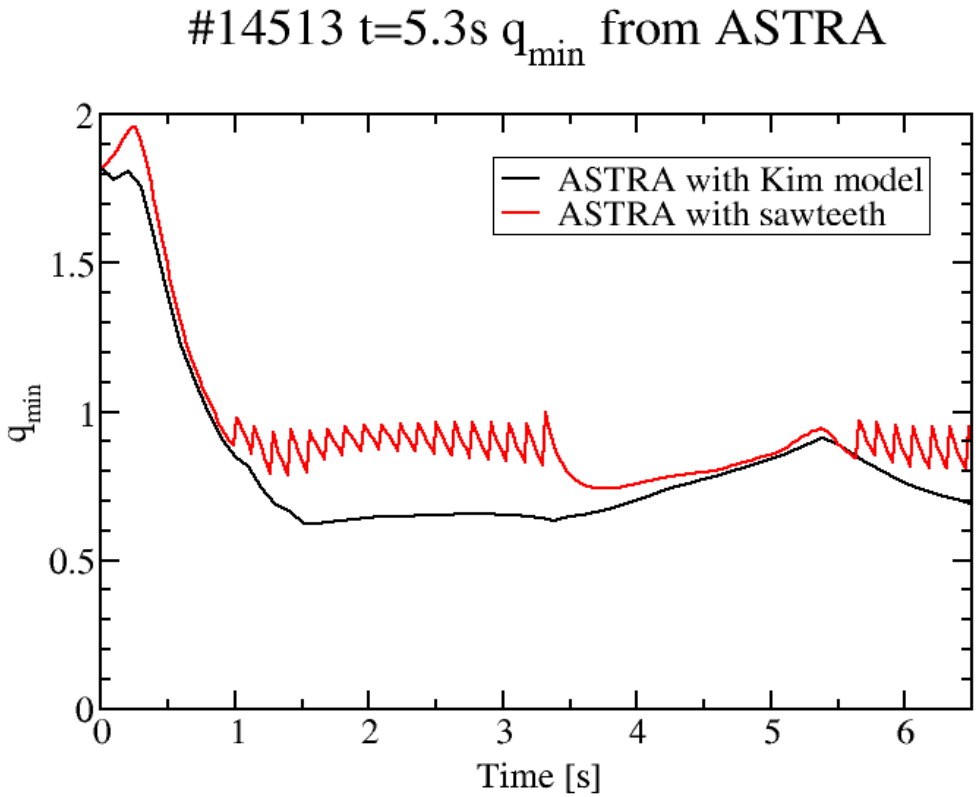
Significant change in q expected

Also MHD is different in one beam case

Strong reduction in (1,1) mode frequency for one-beam discharge

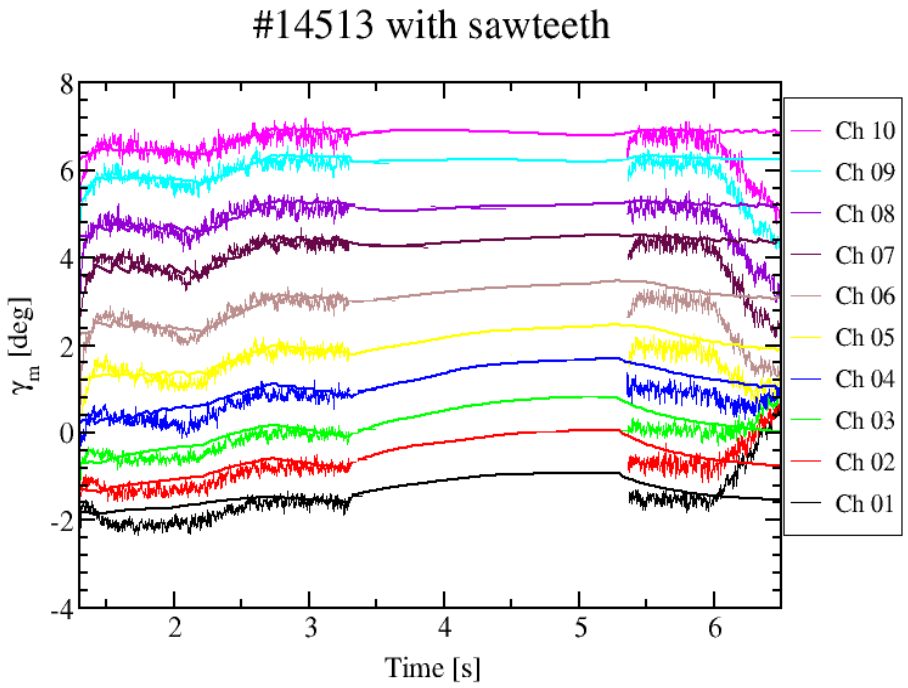


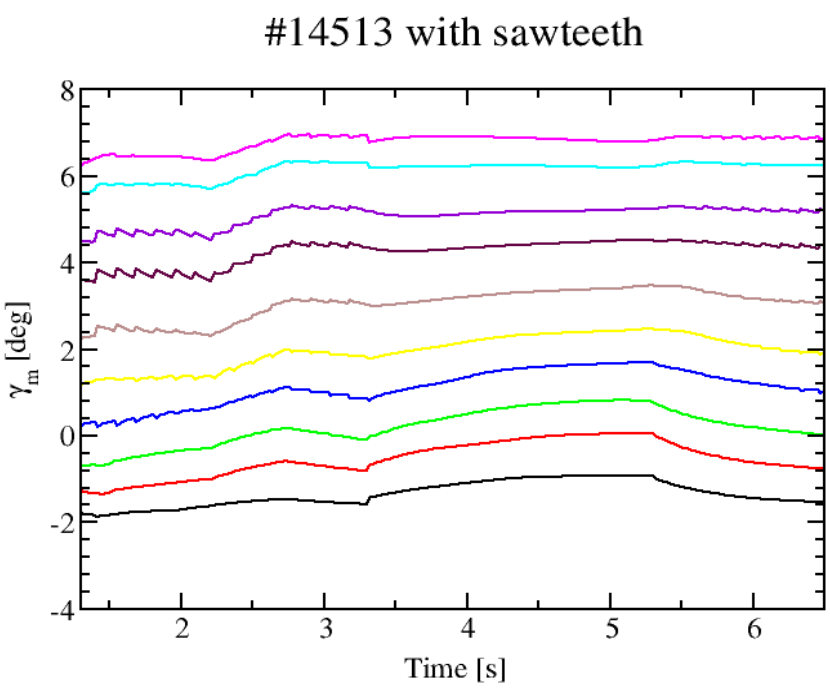
Inclusion of sawteeth in model does not change picture



- q development different with sawteeth
- Model does not full reconnection after given time
- q too low without sawteeth
- Change in q_{min} still significant with off-axis NB

Inclusion of sawteeth in model does not change picture

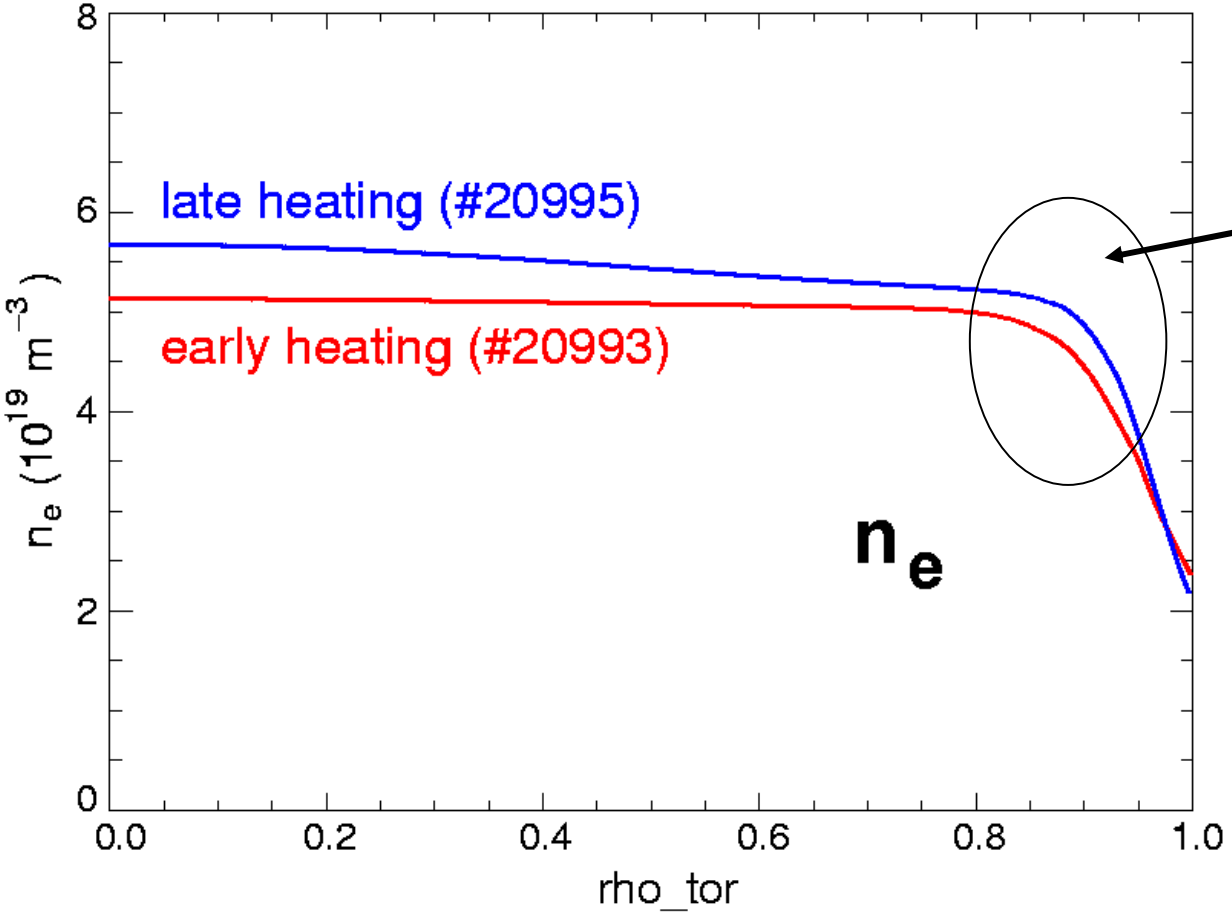




- Difference with off-axis beams still visible
- Offset different
- Raus-scan smeared out

- Sawteeth should be visible in MSE
- Not seen so far in any discharge

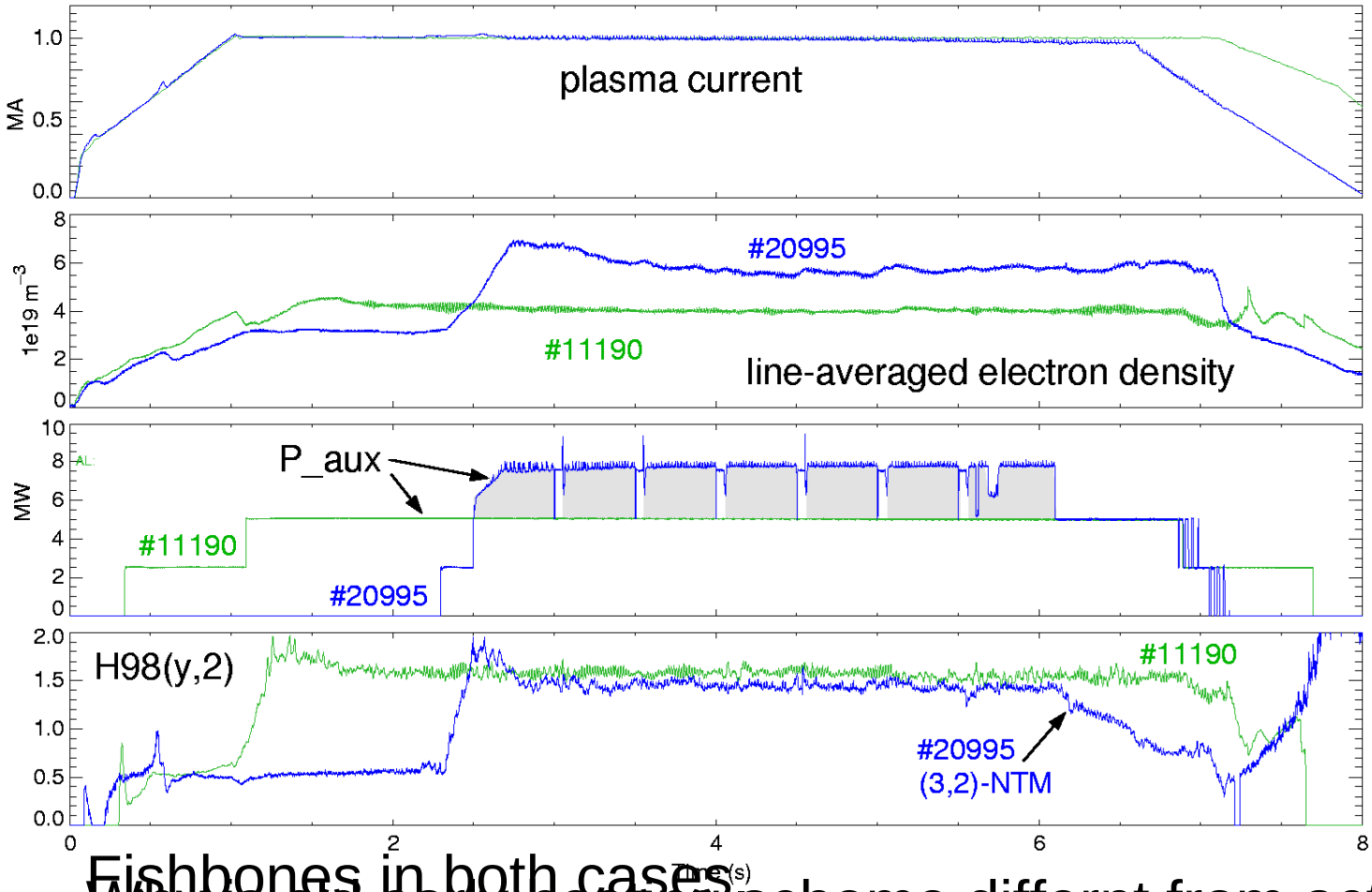
Differences in kinetic data : n_e



significant
good LI-beam data
but no edge T_e, T_i

Effects of H-mode pedestal: talk C. Maggi

Comparison to older improved H-modes



late heating as before

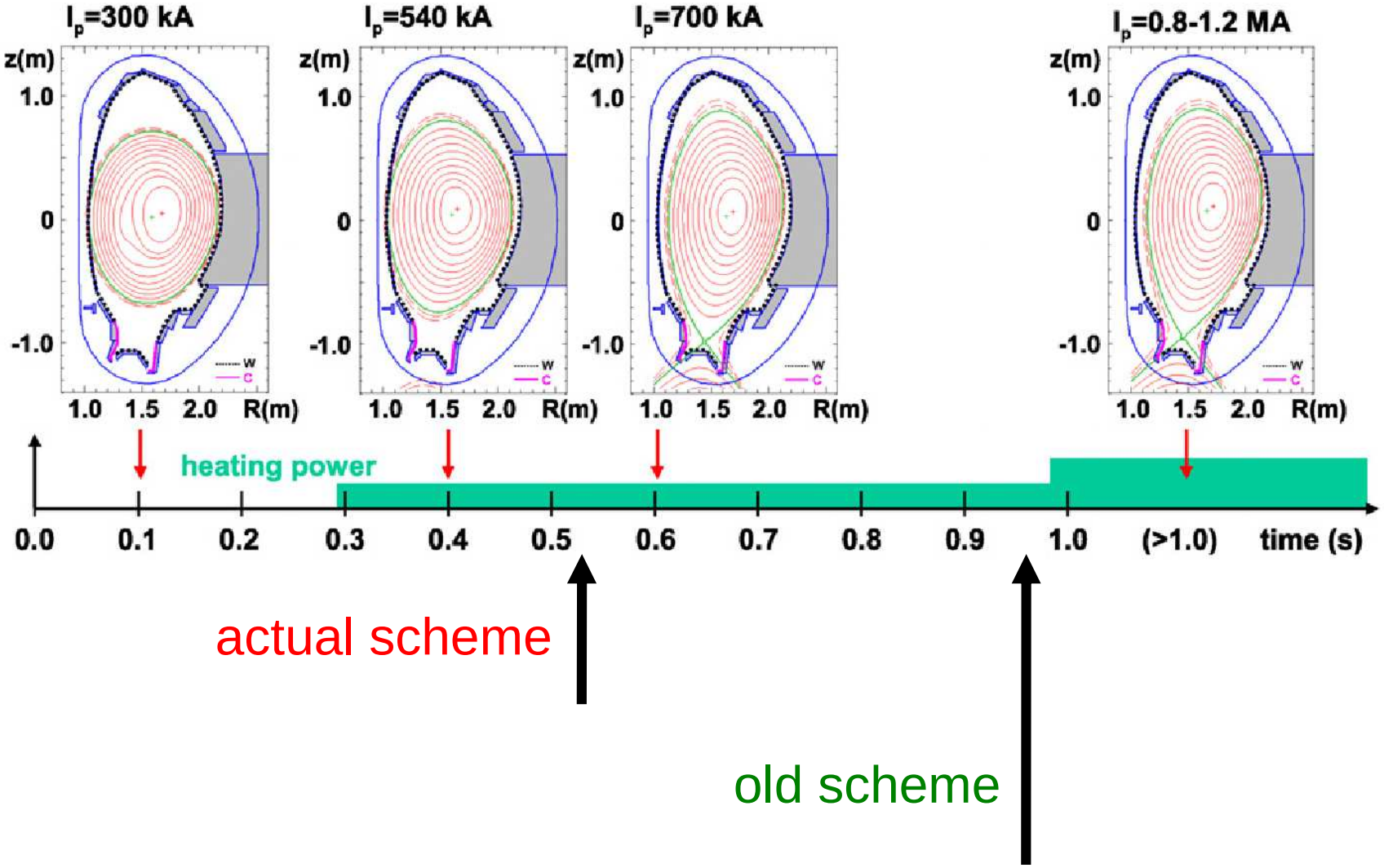
PRL 1999 Gruber et al

I_p, B_t identical

Fishbones in both cases

Why is old early heating scheme differnt from actual one?

scheme of divertor formation



early heating well suited for lower q_{95}

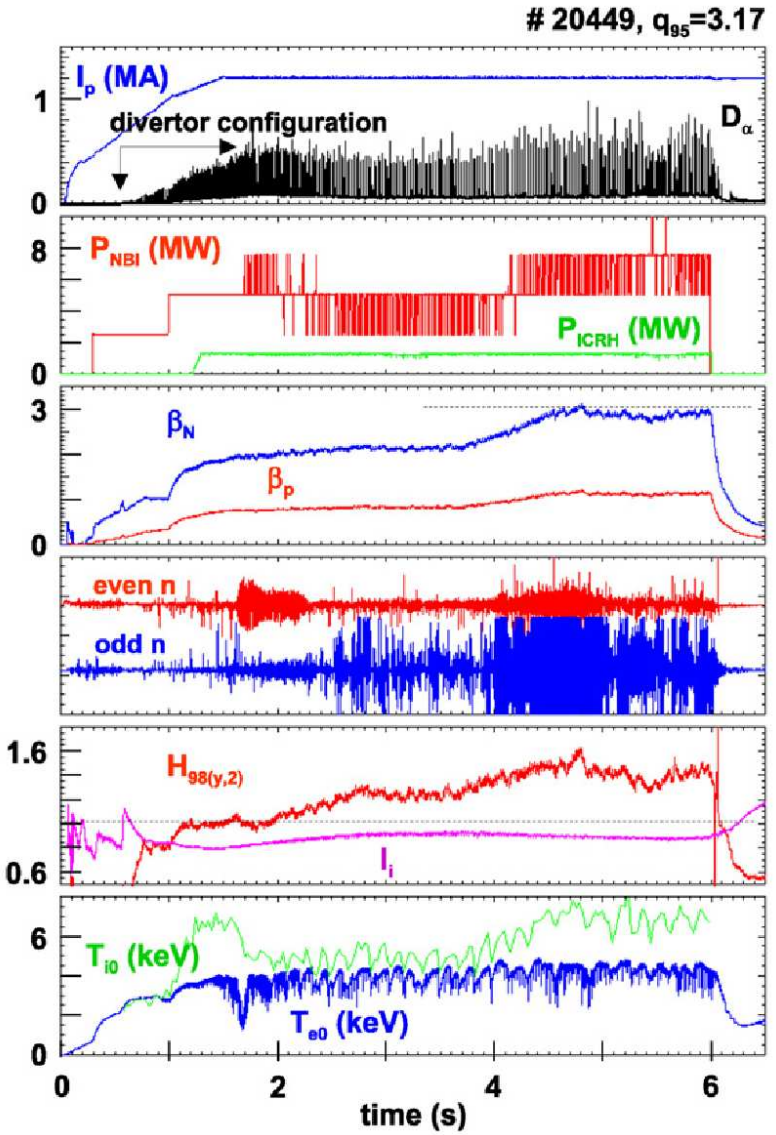
q_{95}= 3.1, early divertor formation

early heating → fishbones

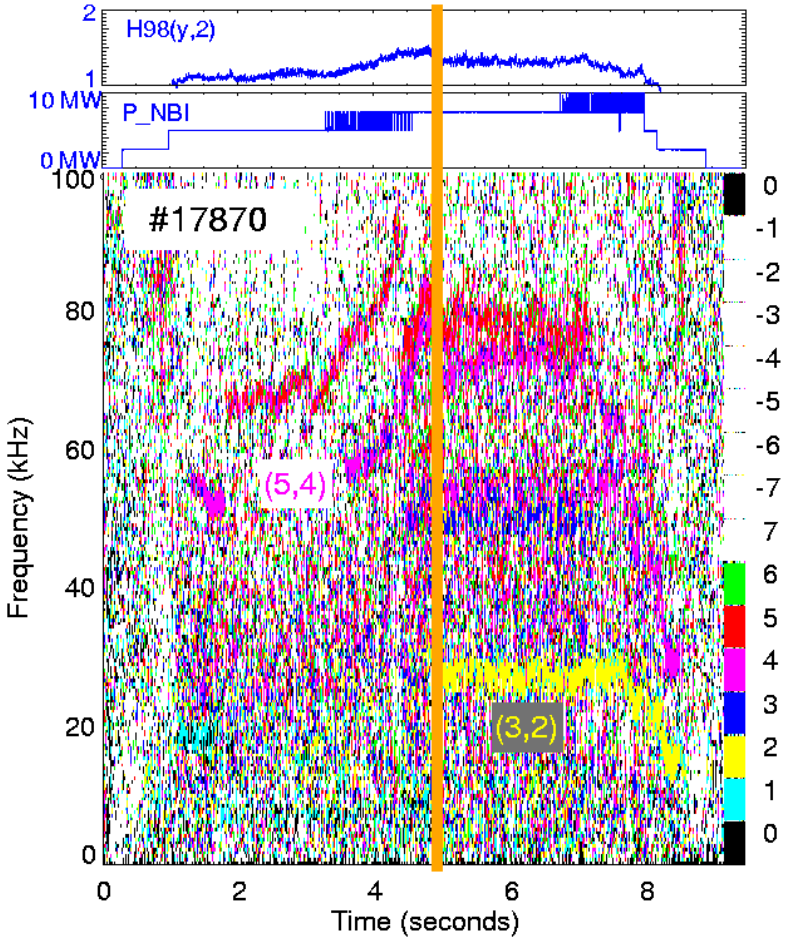
Reason:
Central q < 1.3 after ramp-up ?

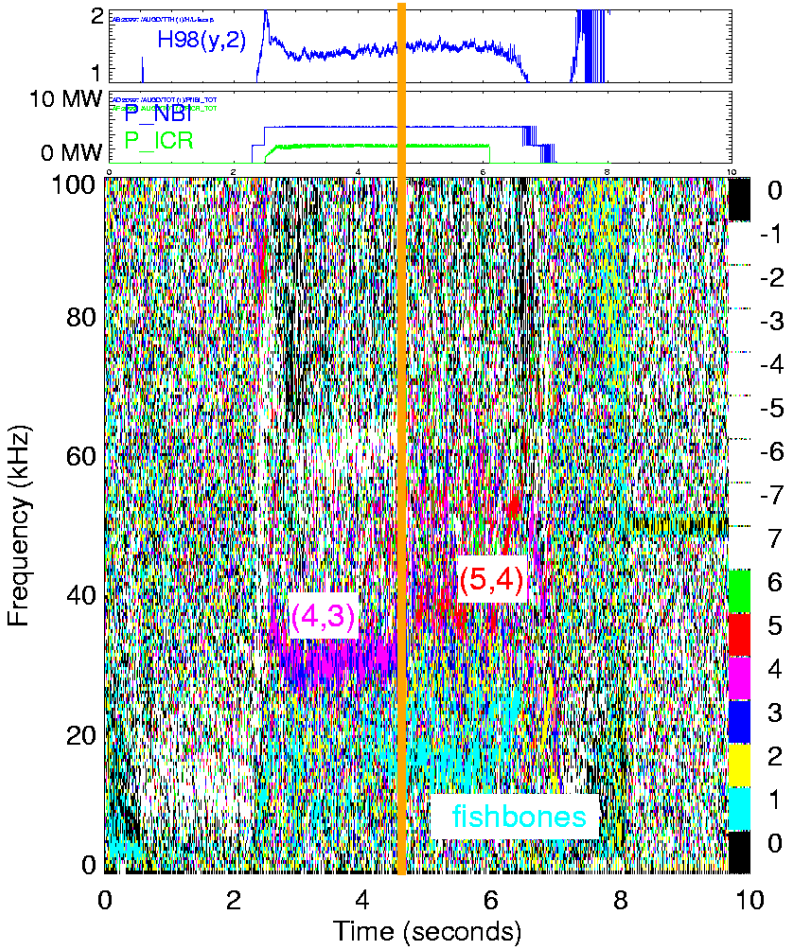
Plausible,
but no MSE for this discharge,
to be repeated 2008/09

Note: high beta compatible
with fishbones

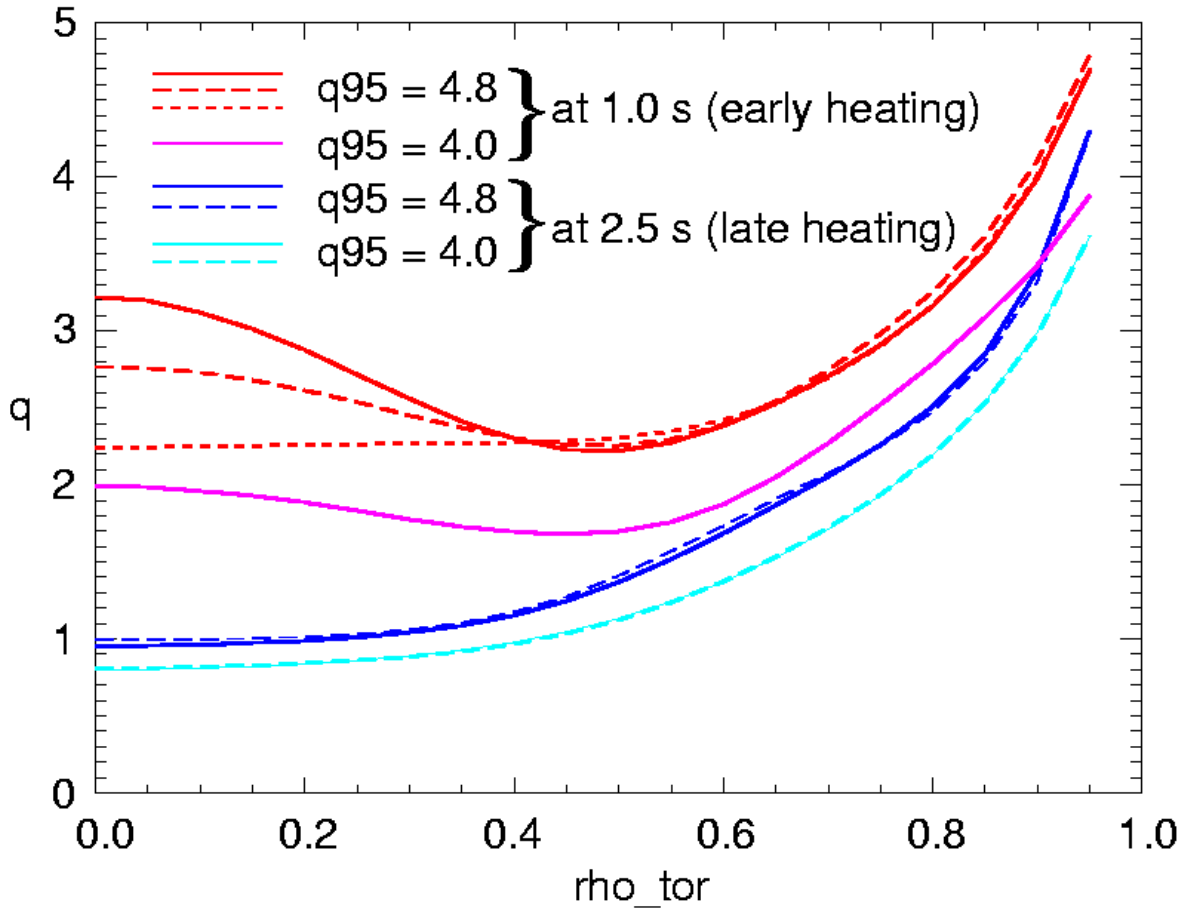


MHD variation during single discharges

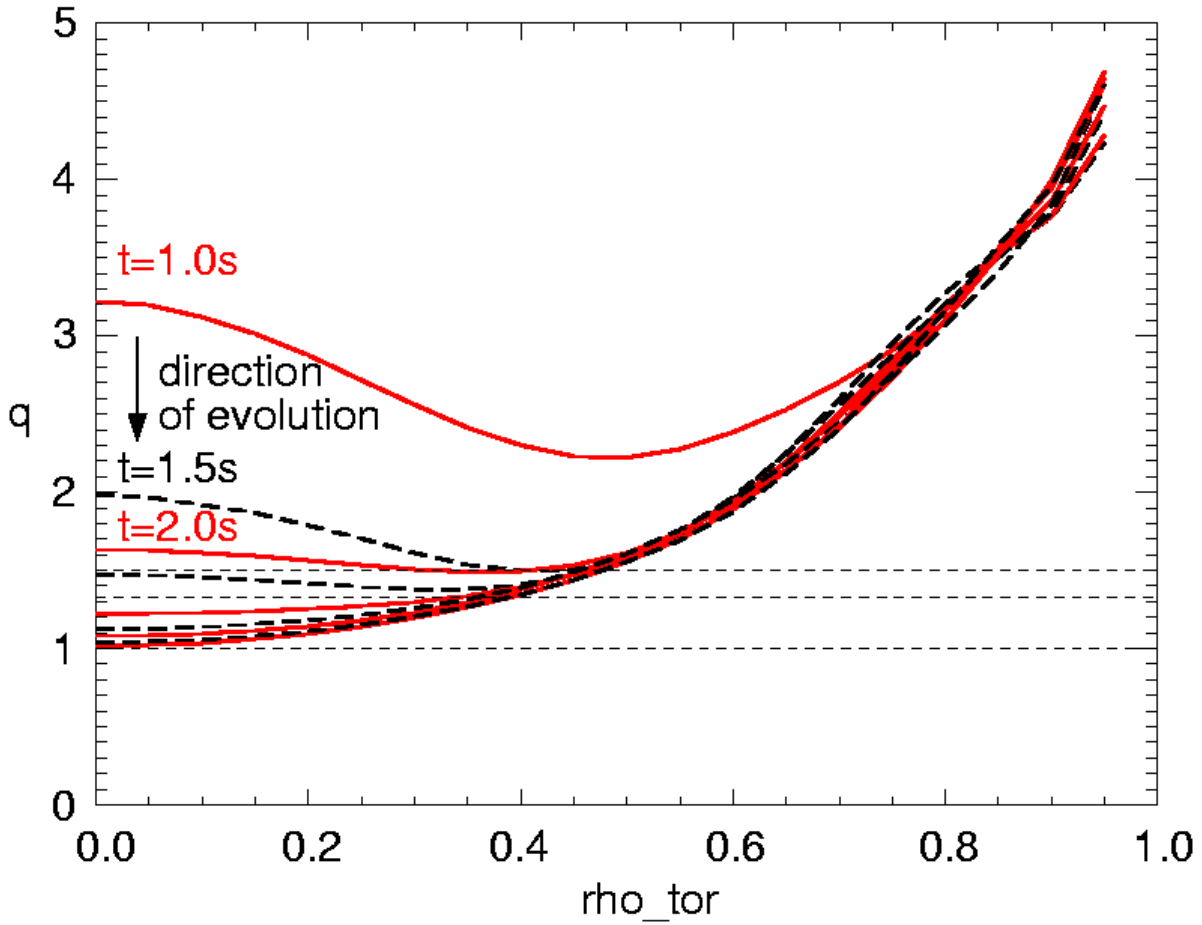




Variation of the q-profile at end of ramp-up

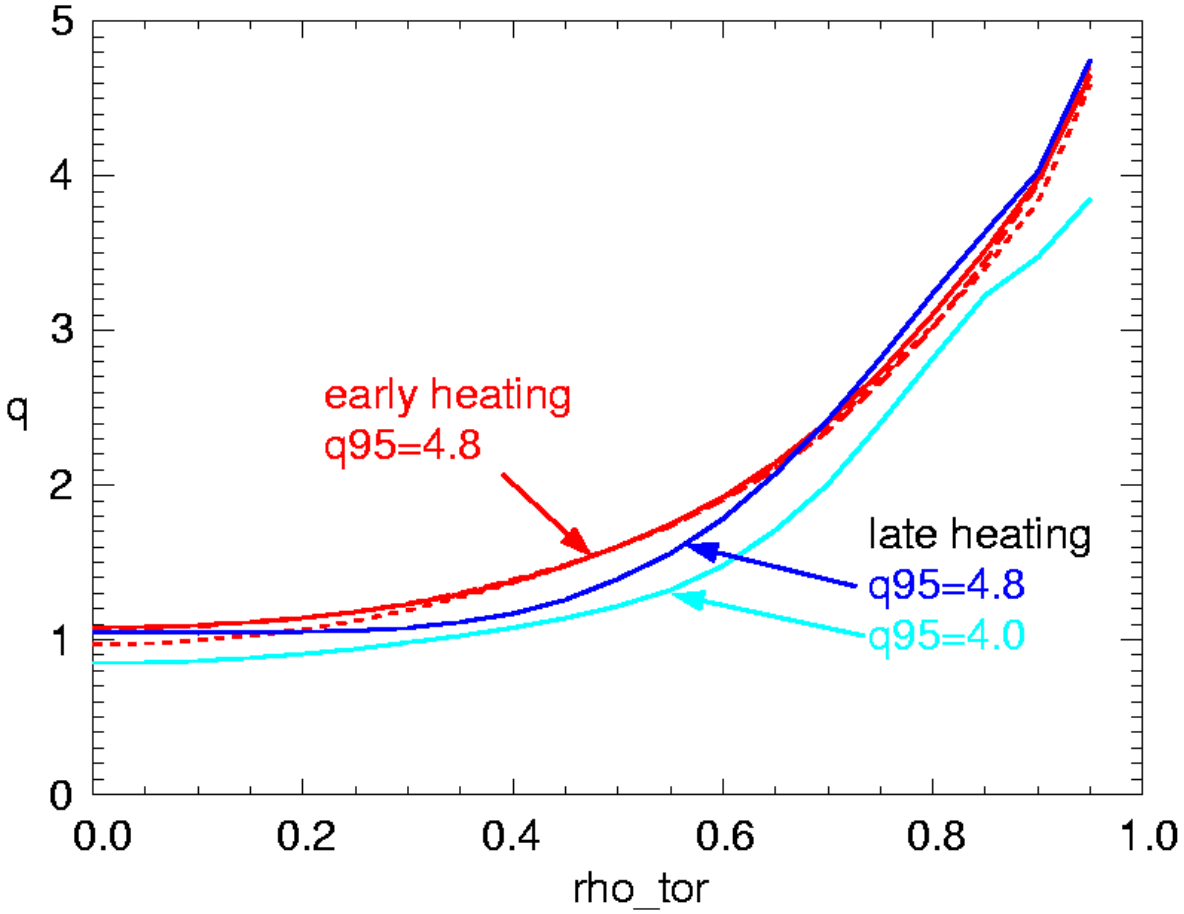


Relaxation of current profile after early heating



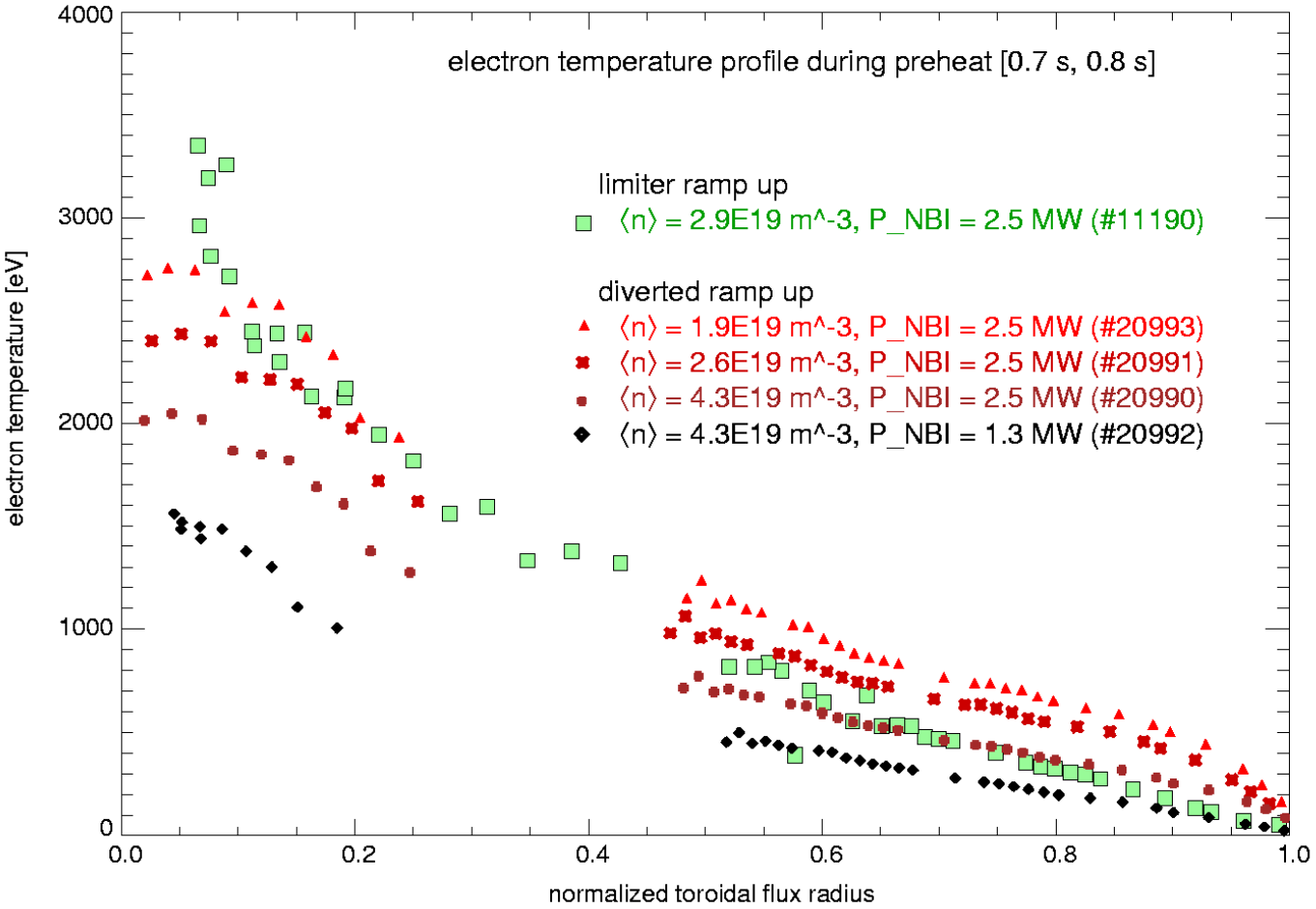
NTMs set in when central q flat and close to 1.5

Equilibrated current profiles



Late heating q-profiles do hardly evolve during main heating
→ always significant shear at q=1.3...1.5

limiter ramp-up: stronger peaked T_e-profiles



More peaked current profile leads to lower central q-values
→ fishbones, better confinement