First results on n=1 and n=2 ELM control on DIII-D & progress on JET

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Motivation

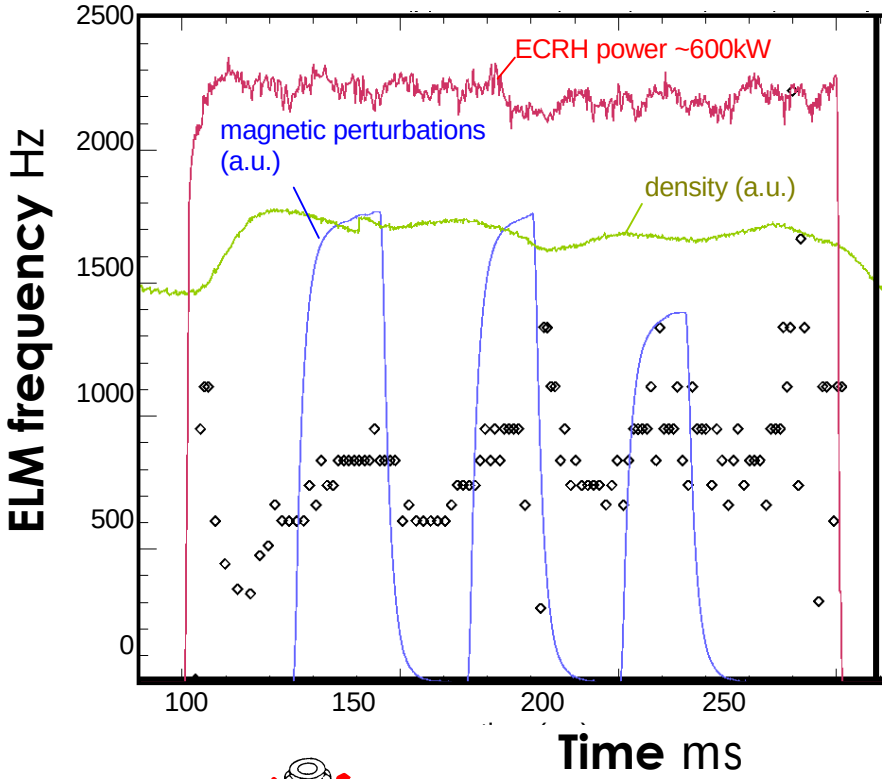
- **DIII-D made excellent progress with type I ELM control using n=3 fields**
  - Seems to be consistent with an edge ergodisation process
- **But a number of questions still arise:**
  - What are the physics mechanisms?
  - What levels of ergodisation is required and where?
  - How to broaden resonances and put on a more robust footing?
- **Studies with n=1 and n=2 fields may open up parameter space and also address key physics questions**
- ***ITER…***

Contents

- **Background**
  - Early trials on COMPASS-D and JET highlights
- **Progress on JET**
  - New results with higher shape, AT and n=2
- **DIII-D experiments**
  - Modelling studies to show what's possible
  - n=1 results with pure I and I+C coils
  - n=2 complete ELM suppression?

Early COMPASS-D n=1 ELM results

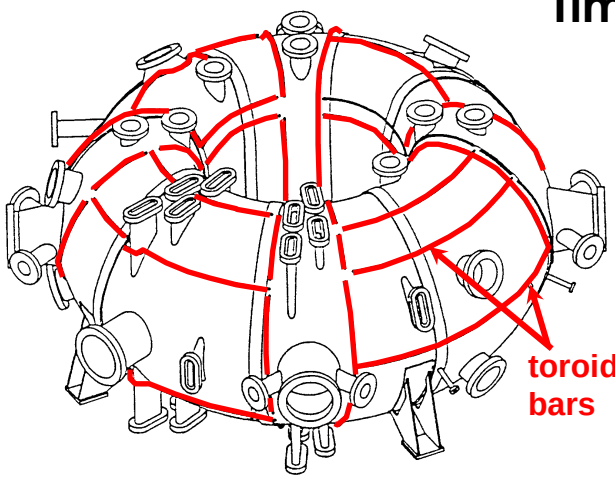
m/n	Br(G/kA)
6/1	0.4
5/1	1.0
4/1	1.5
3/1	1.2
2/1	0.2
1/1	1.7

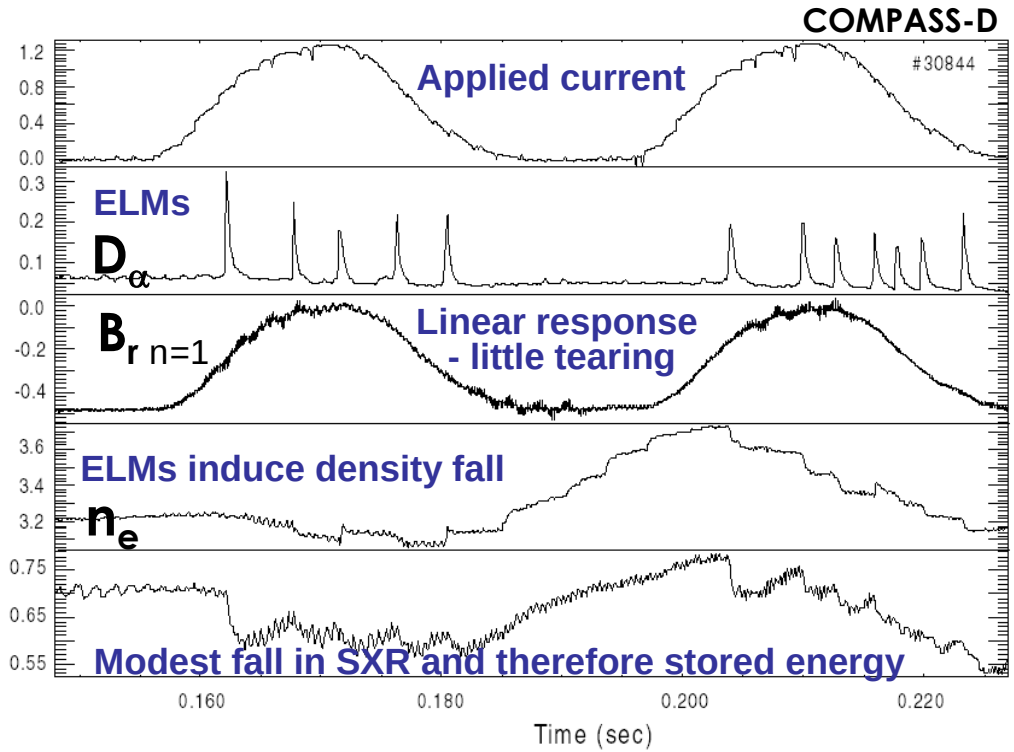


Apply m=3,4,5:

← Type III ELMs freq increase

↓ ELMs triggered in ELM free





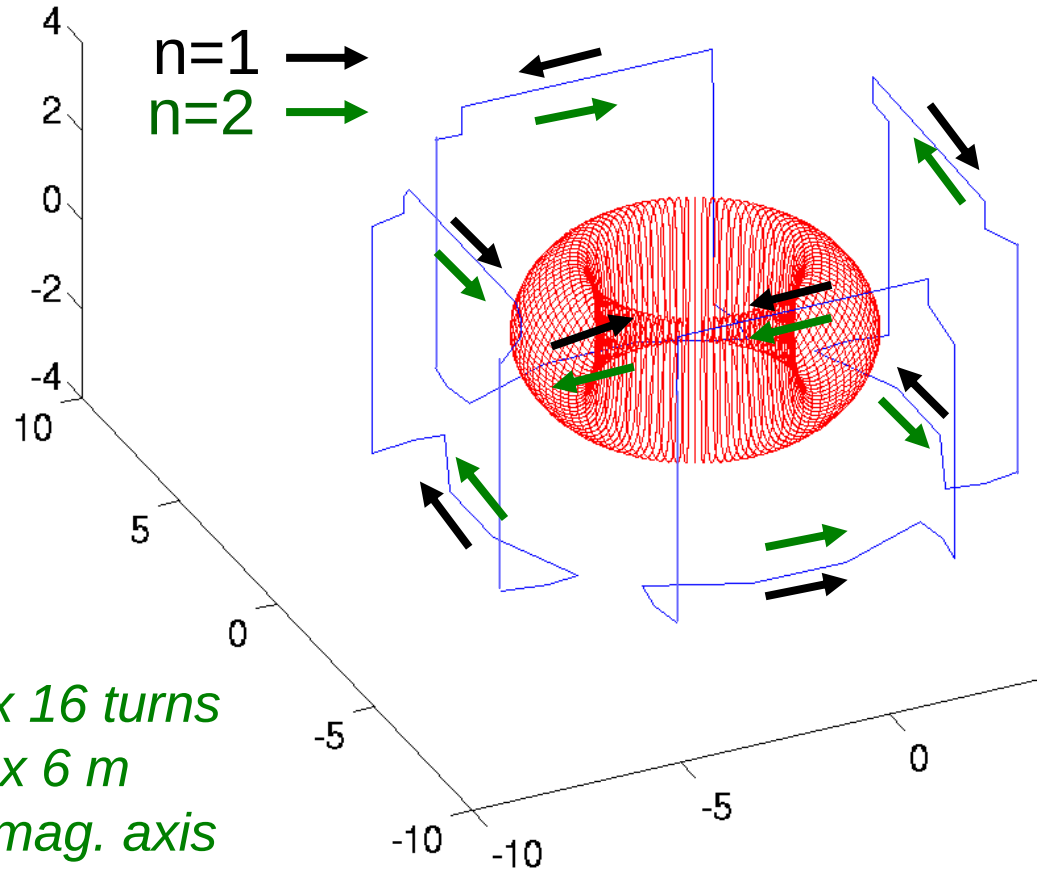
JET RMP fields

***n*=1:**

- Weak edge ergodisation
- Plasma braking
- Seeding of locked modes

***n*=2:**

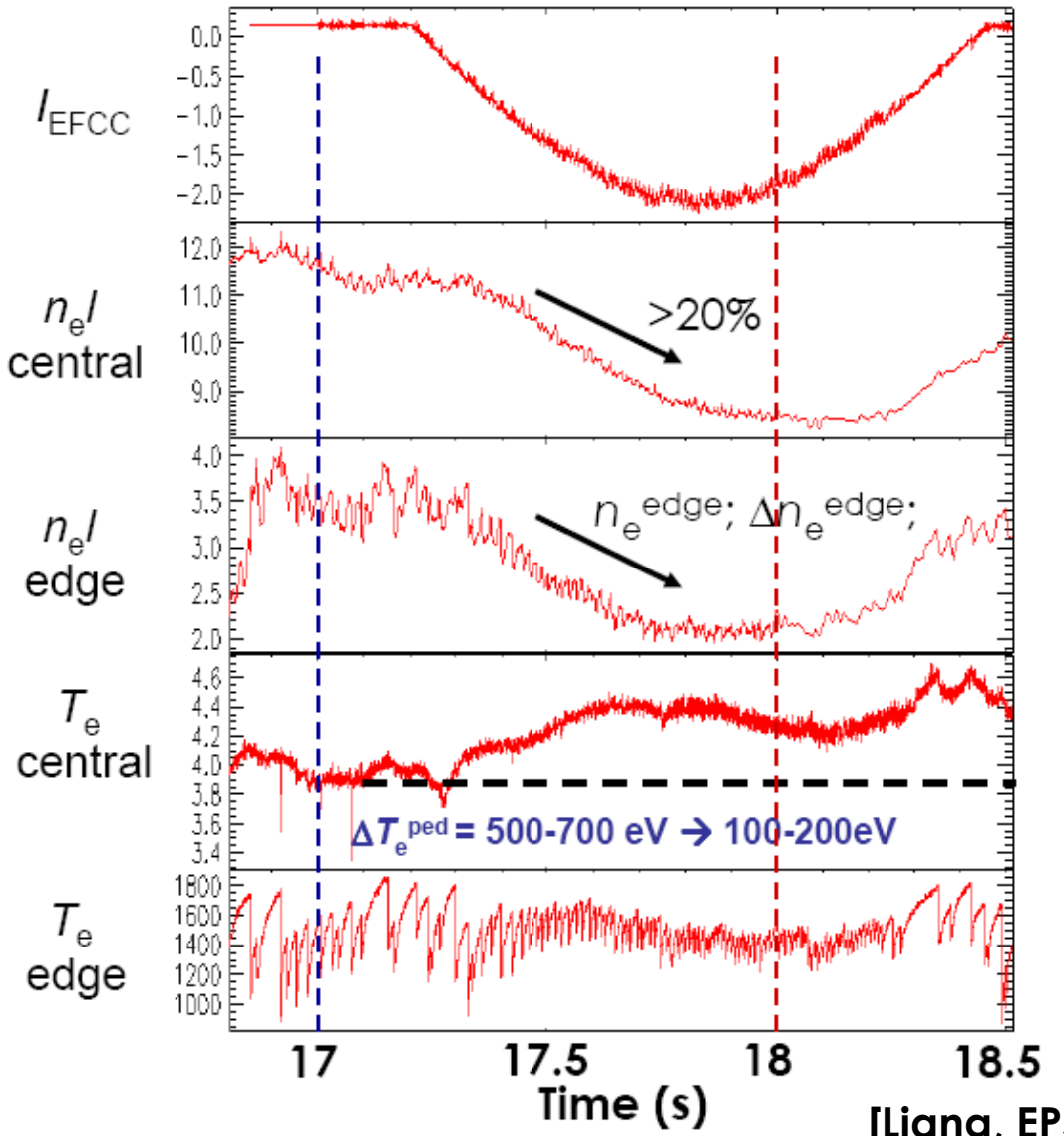
- Good edge ergodisation
- Small influence on core plasma



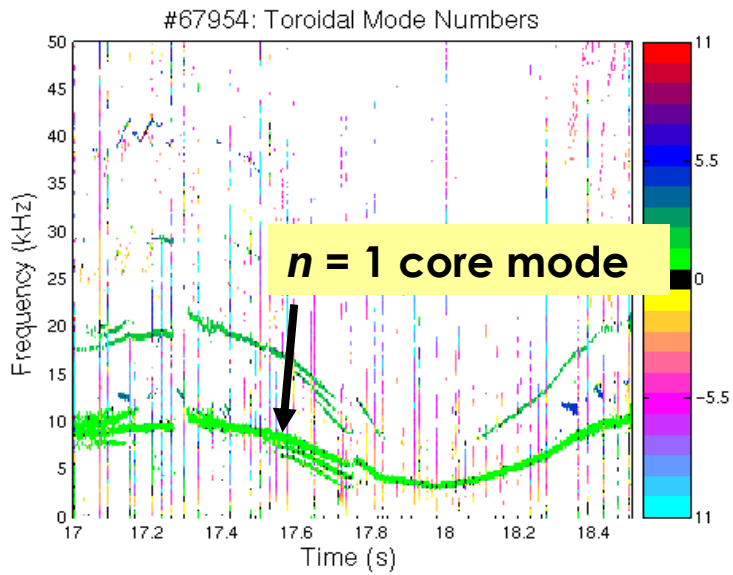
I_{Coil} ≤ 3 kA x 16 turns
Size ~ 6 m x 6 m
~3 m from mag. axis

[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: *n*=1 field results



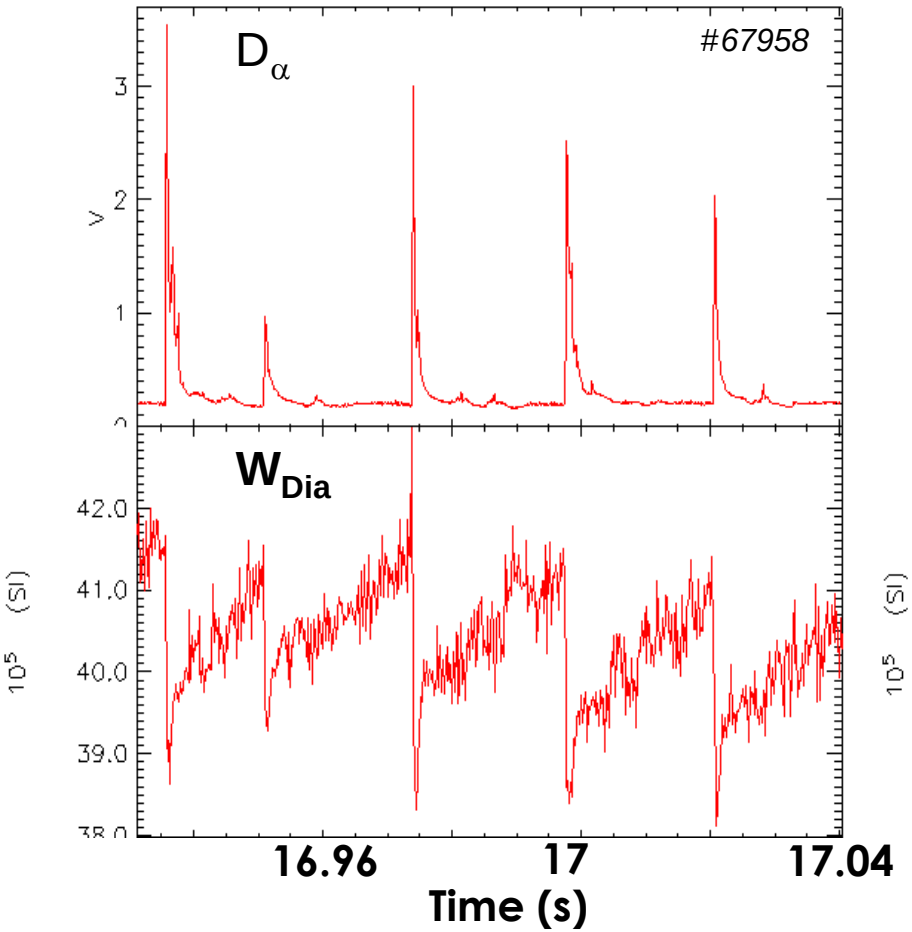
- **Density reduced**
- **Temperature rise**
- **Rotation strongly reduced**



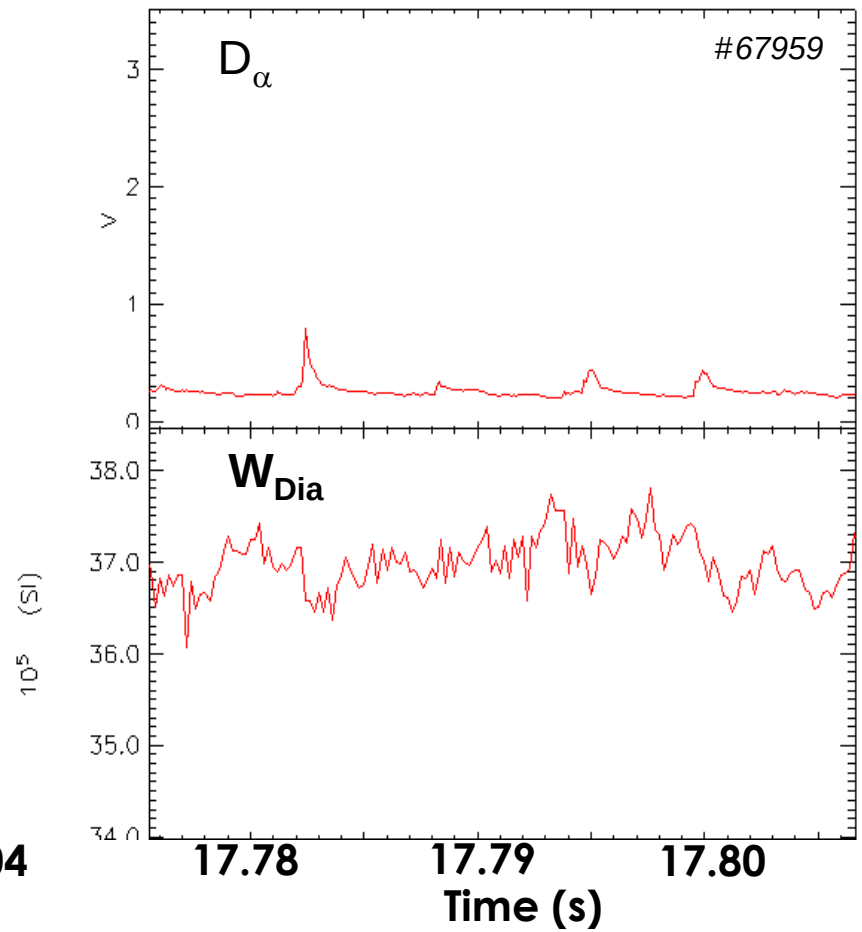
[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: Reduction in energy loss $\Delta W/W$ of ELMs

without EFCCs

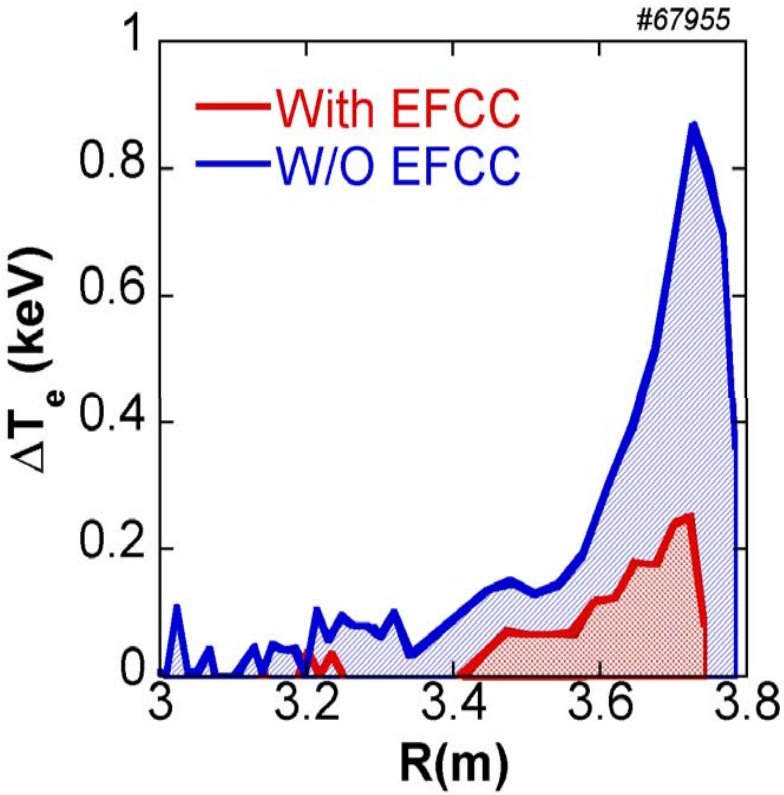


with EFCCs



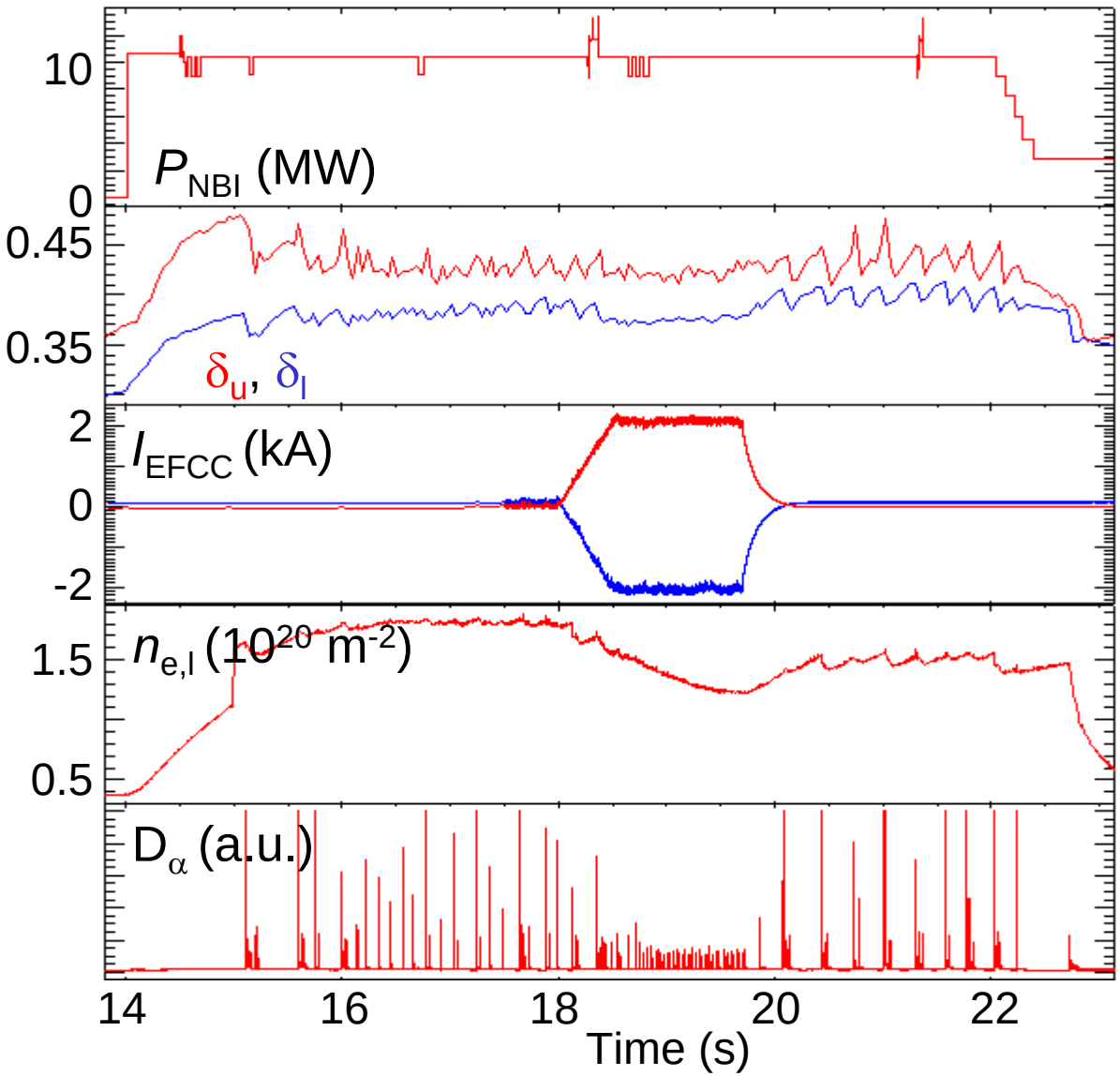
[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: ELM T_e perturbation smaller with RMP



[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: Result extended to high shape…



HT-3

"ITER-like"

EFCCs in *n*=1

I_p = 1.8 MA

B_t = 2.05 T

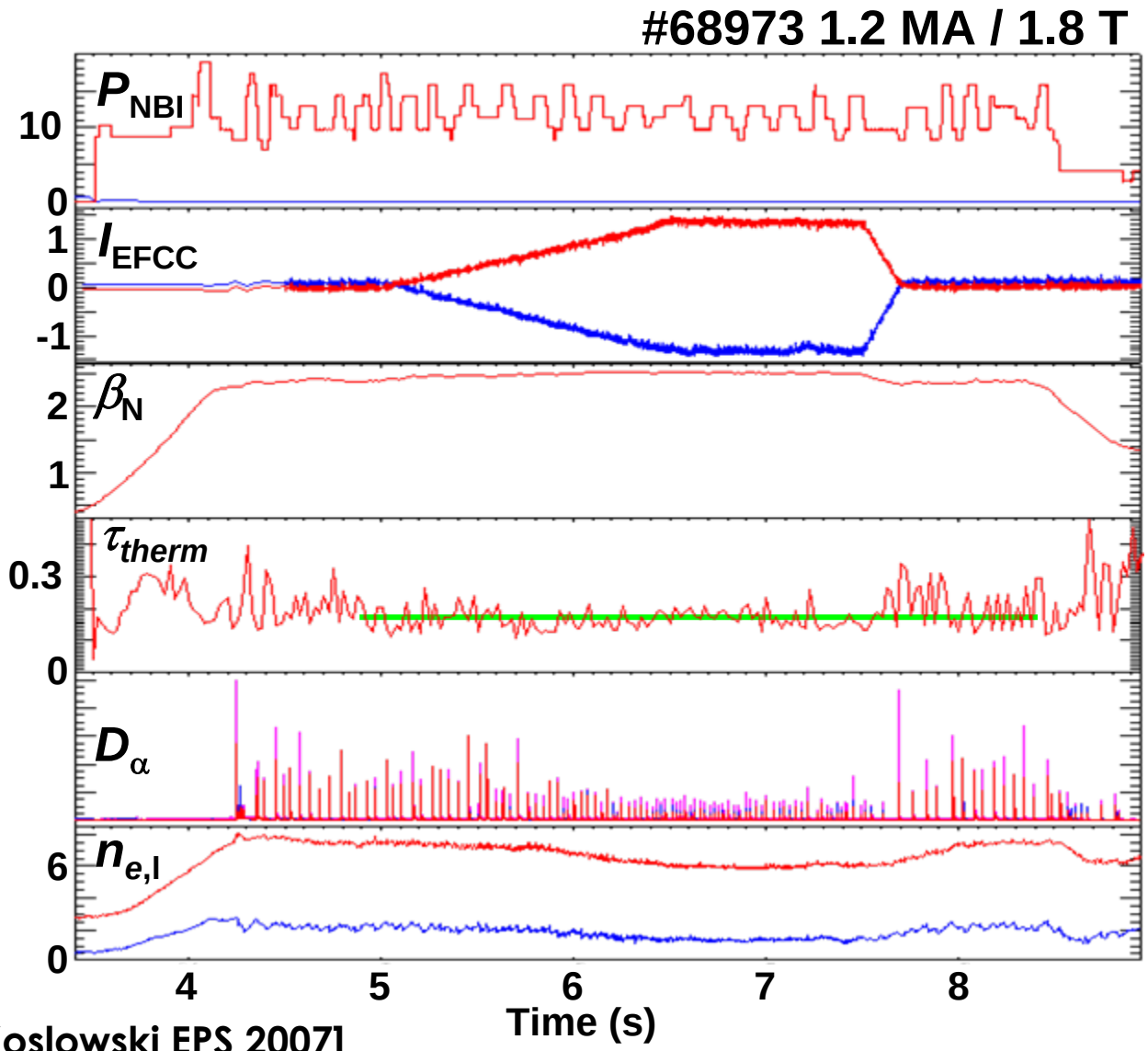
P_{NBI} = 10.4 MW

[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: …and applied in high β AT plasmas

β_N ~ 2.5, n=1 field:

- Confinement maintained
- Density drops ~20%



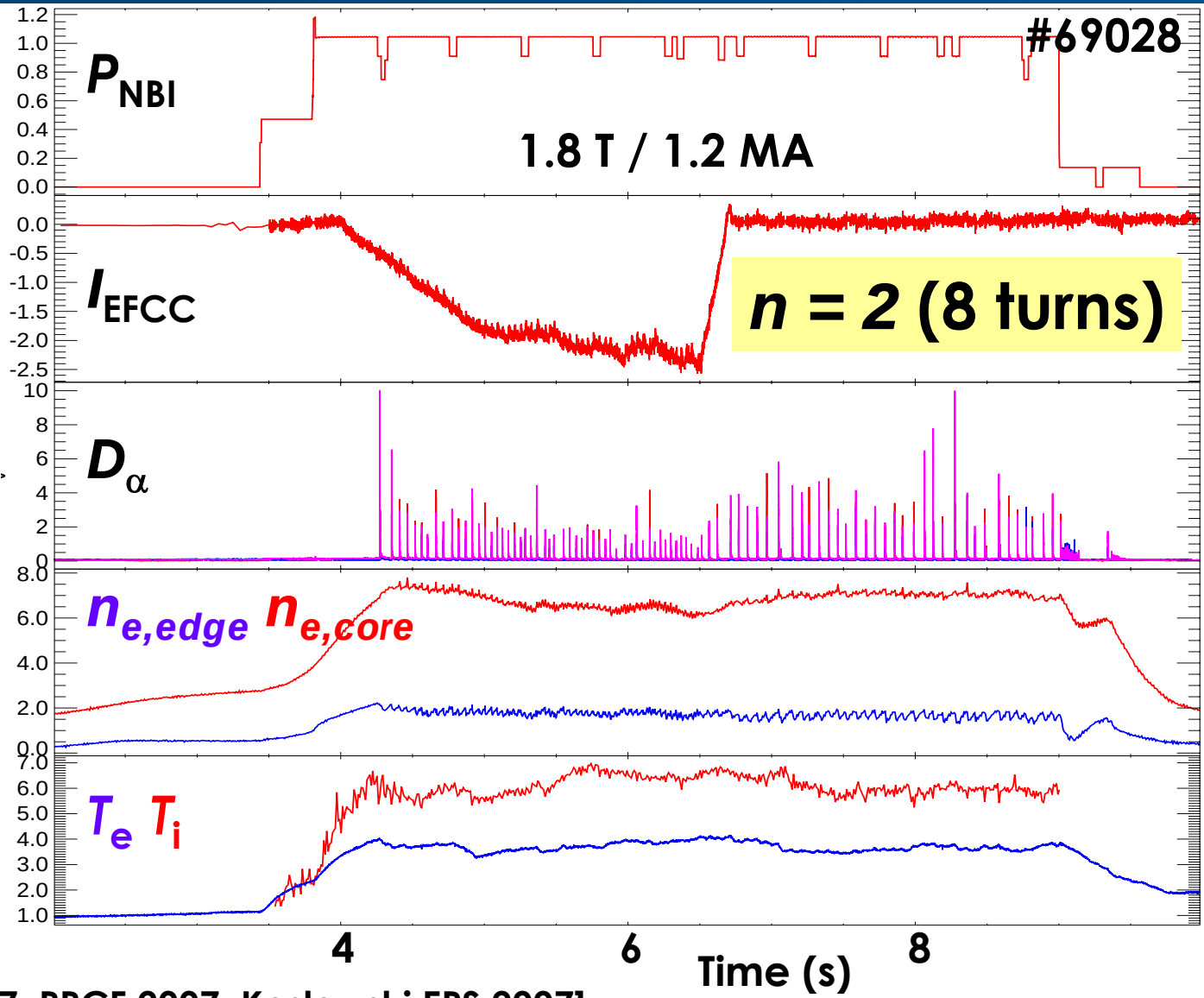
[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: First tests of *n*=2 EFCCs in high β scenario

β_N~no-wall limit:

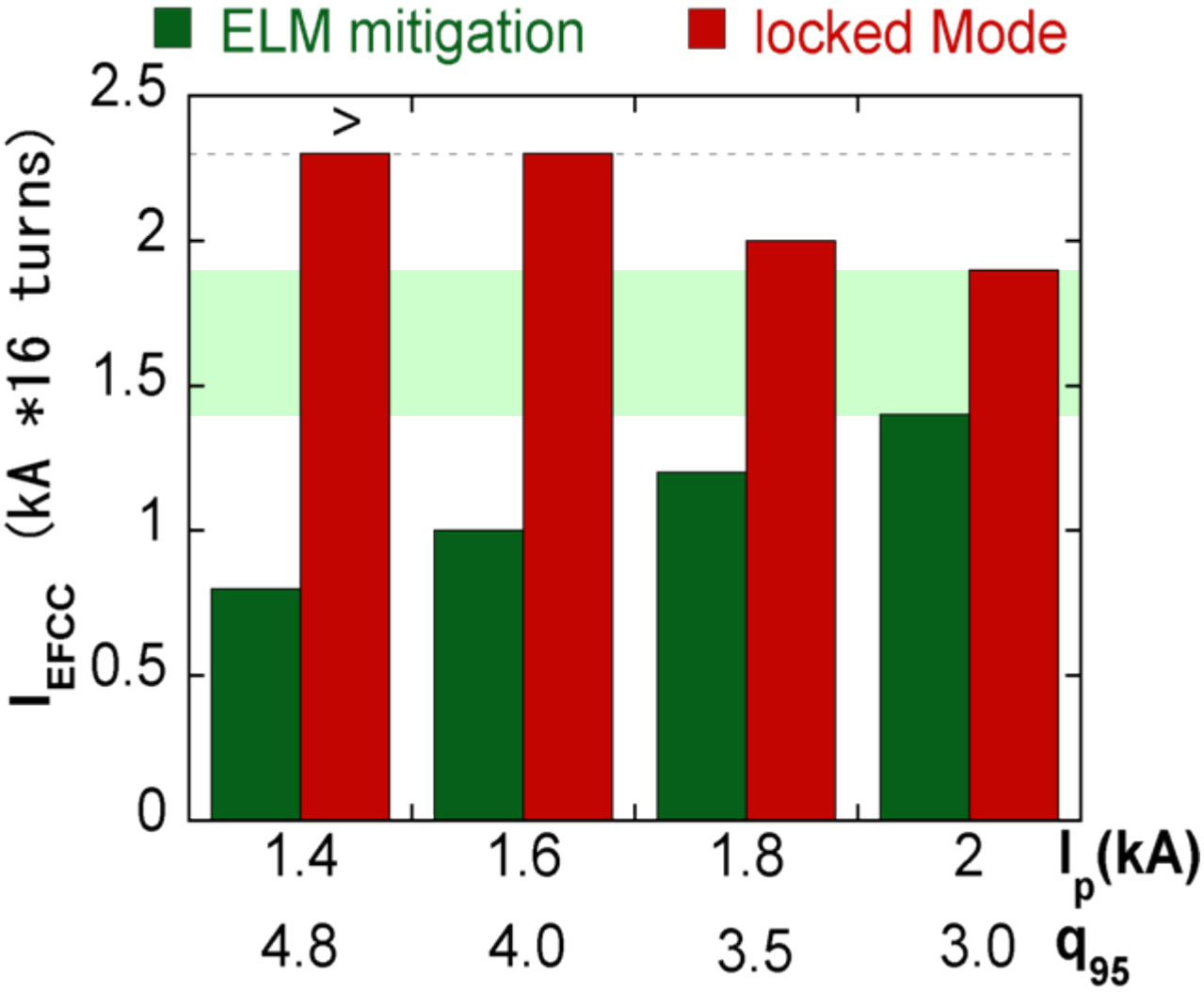
- See 'usual' effect on ELMs, ne, Te
- Though weak as just first test with 8 turns

More in 2008…



[see also Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

JET: q_{95} range - locked modes are an issue, but operational window exists



B_t = 1.84 T

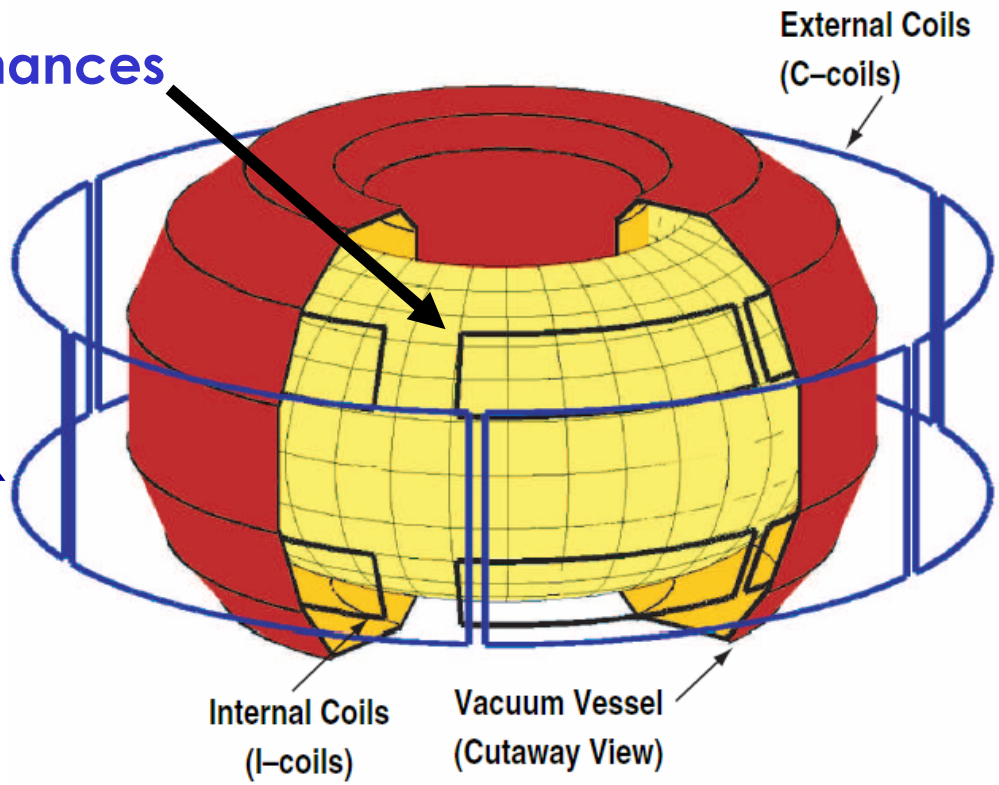
C_SFE_LT

[Liang, EPS 2007, PPCF 2007, Koslowski EPS 2007]

DIII-D brings unique capability to this field

Interplay of I coils and C coils allows us to change balance of field harmonics:

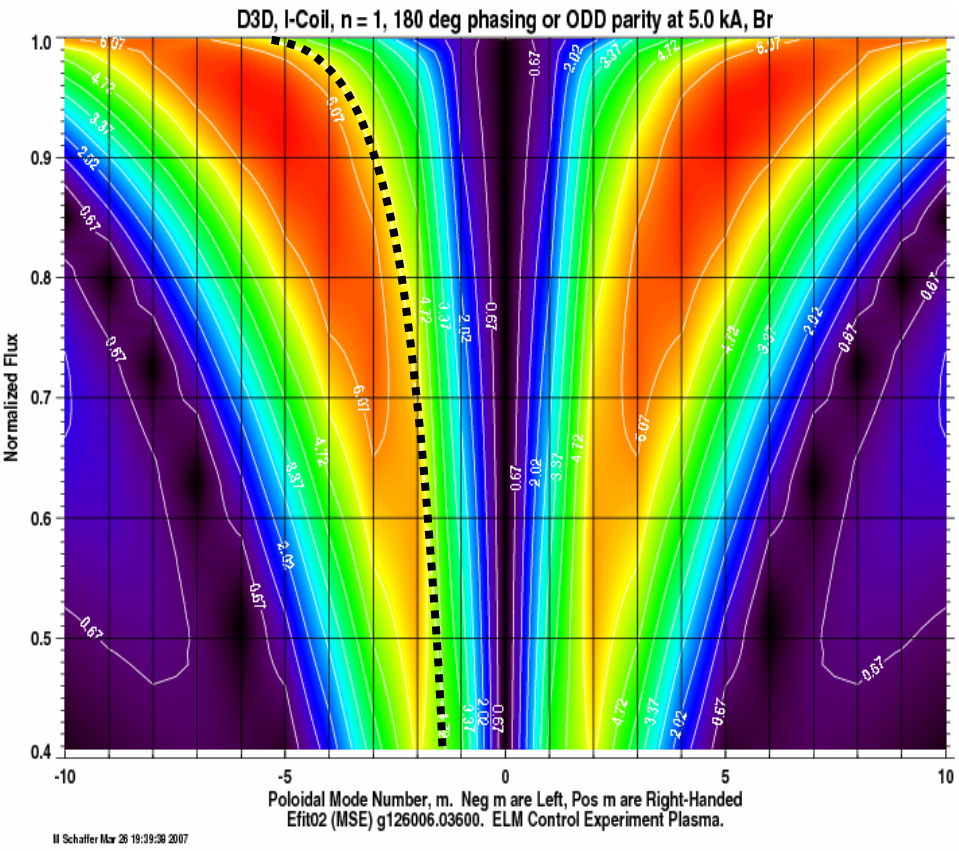
- I coils make strong edge resonances
- Changing I phasing can vary core:edge mix
- C coils can directly cancel out core resonances…
- … and also impact non-resonant fields

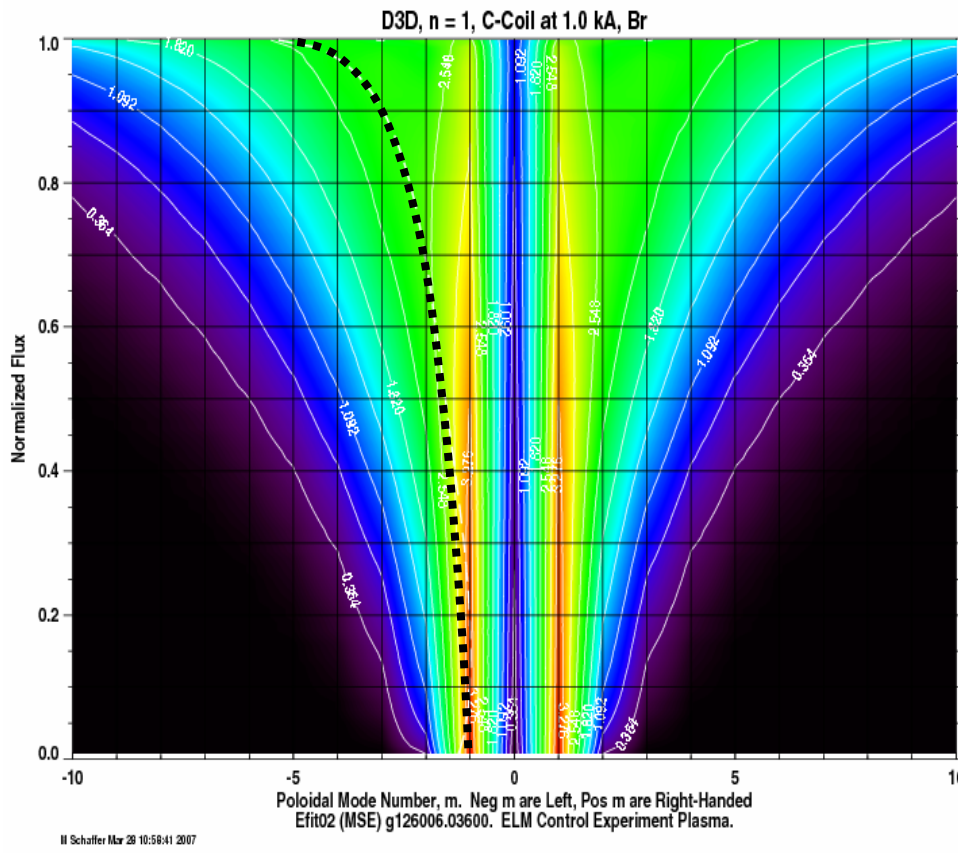


'Proof-of-principal' type scans to see what these do…

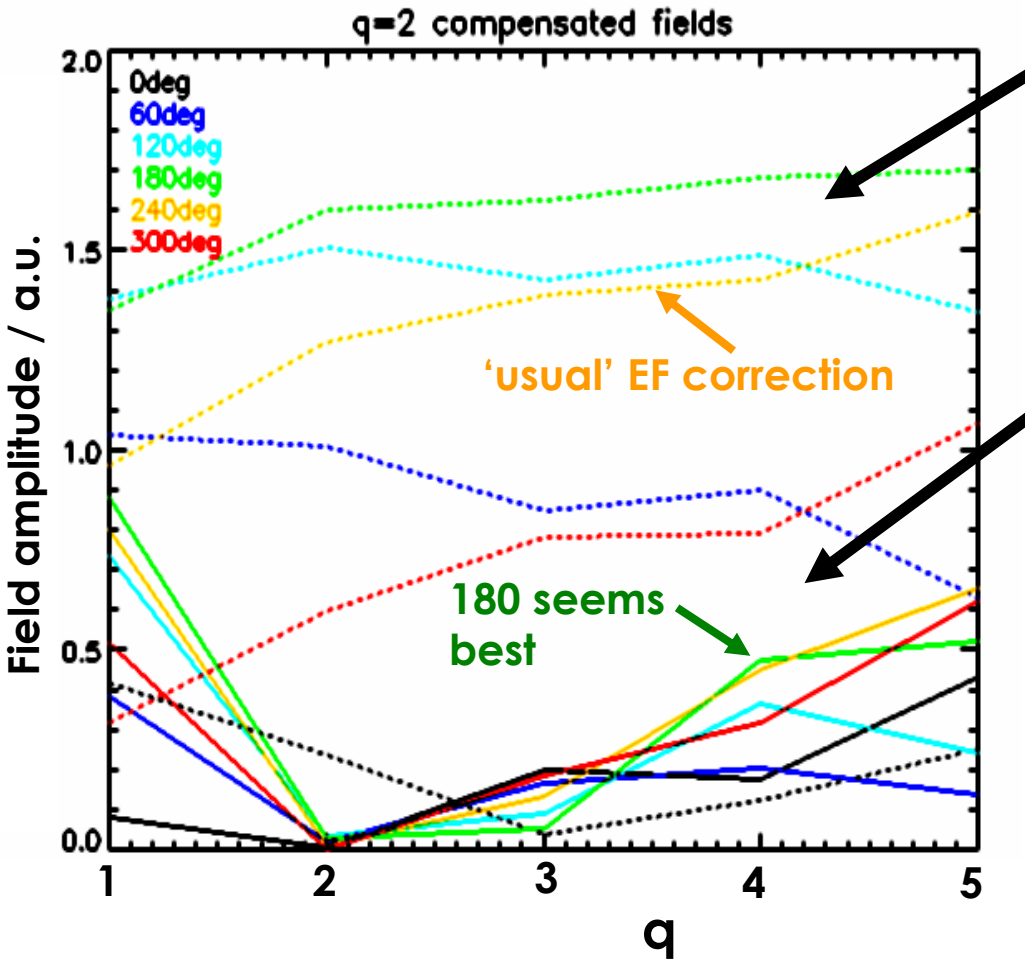
DIII-D Modelling of I and C coil n=1 fields

- **I fields introduce strong edge components:**
  - though Chirikov only just >1
- **C fields strongly core resonant:**
  - Can use to remove I coil core resonances





Field scans possible on DIII-D



Pure I fields (dotted):

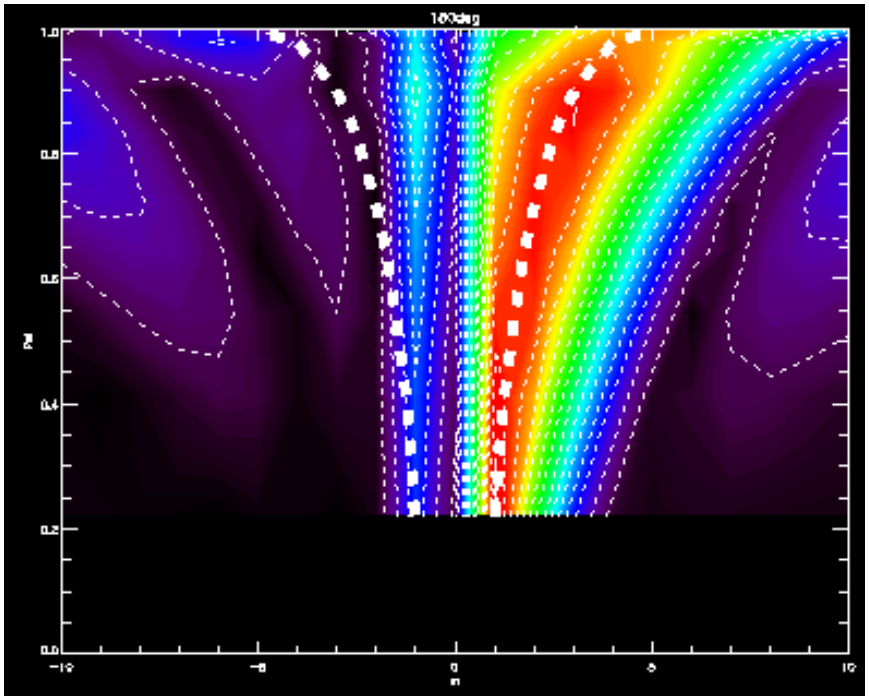
- Different I phasings alter core:edge mix

Cancel 2/1 resonance with C coils (solid):

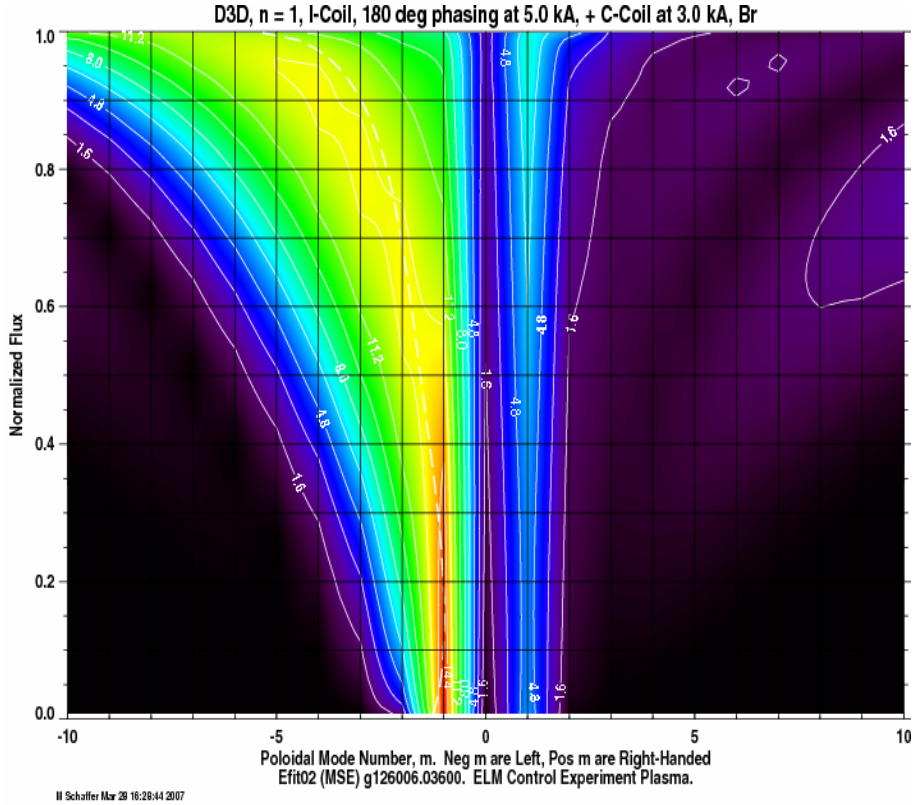
- Leaves residual edge field
- …or can rotate phasings to boost edge field…

Combining Cs and Is (180 phasing)

- Cancelling core harmonics leads to strong non-resonant field:



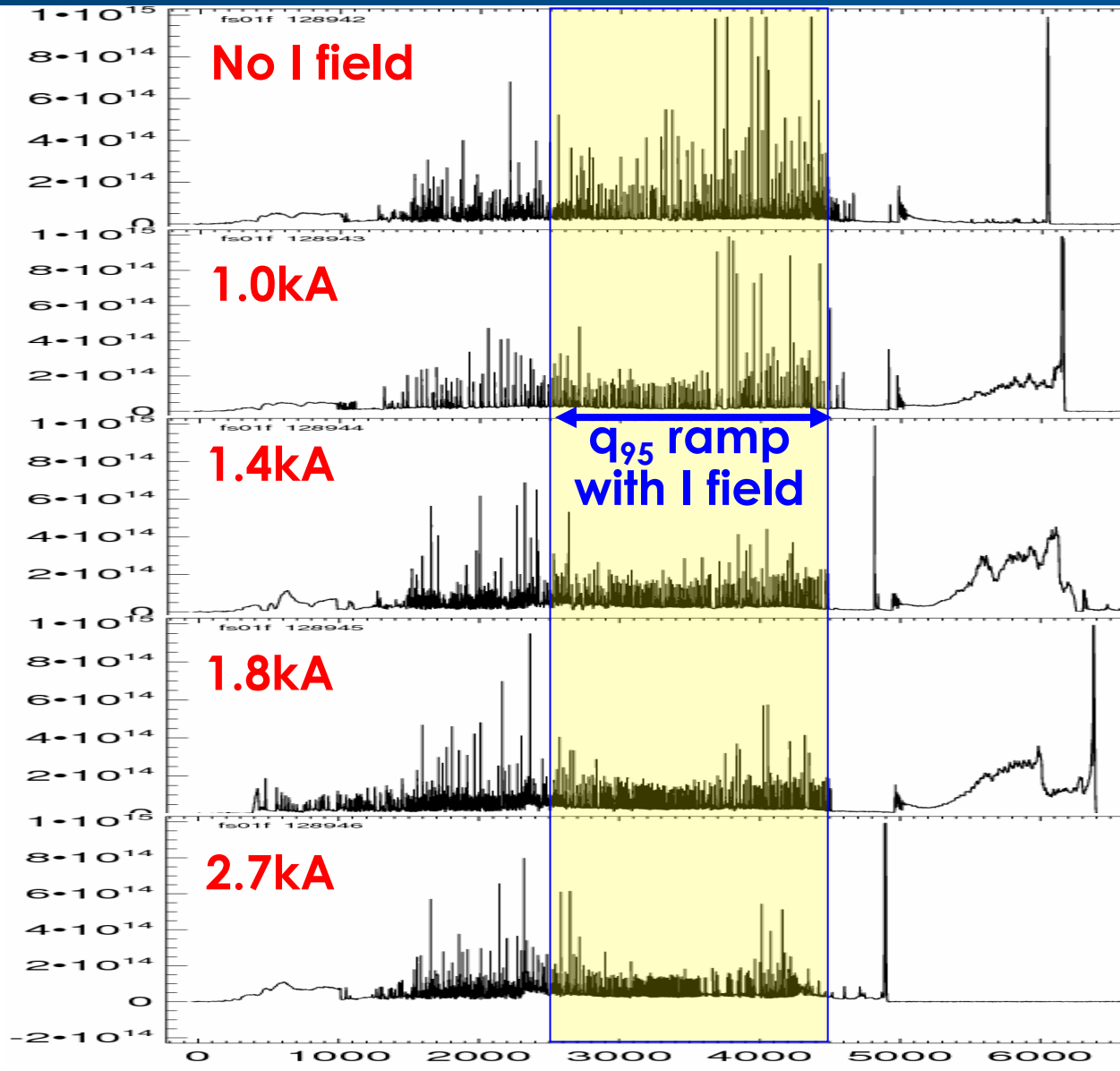
- Or different C phase can kill non-resonant field and enhance edge fields:



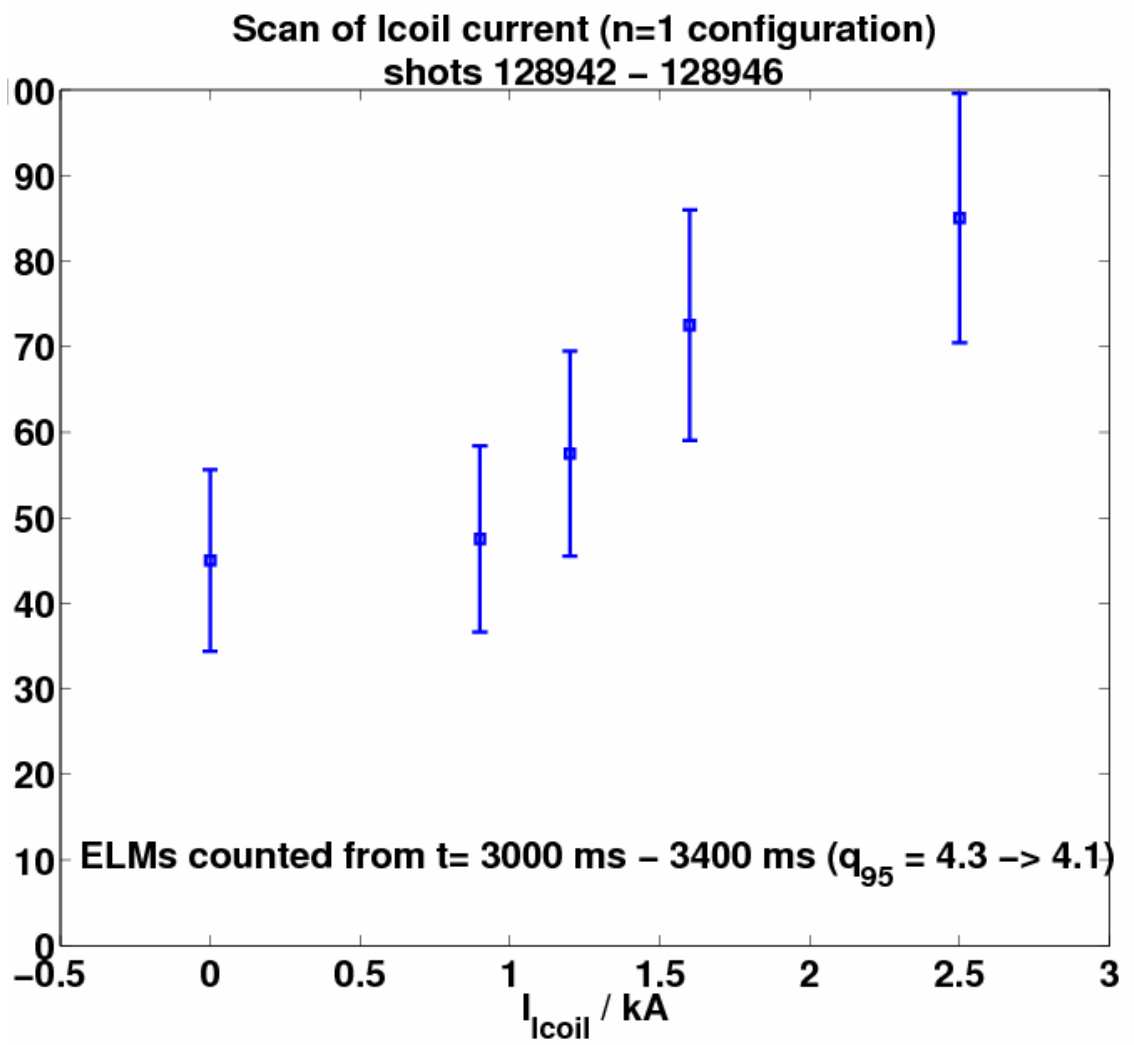
Pure I field tried first in q_{95} ramps:

q_{95} ramp 4.7→3.5:

- Dα amplitude reduced
- ELM frequency increased
- Particular affect around 3200ms, q_{95}~4.25

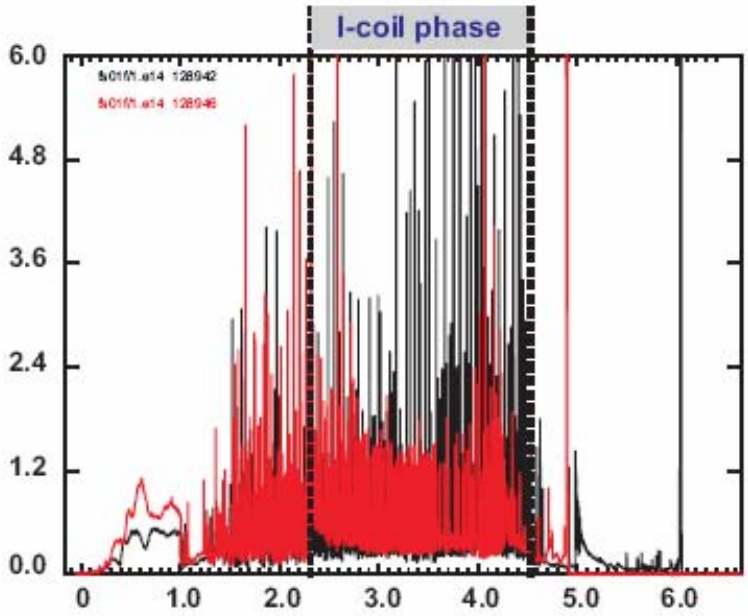


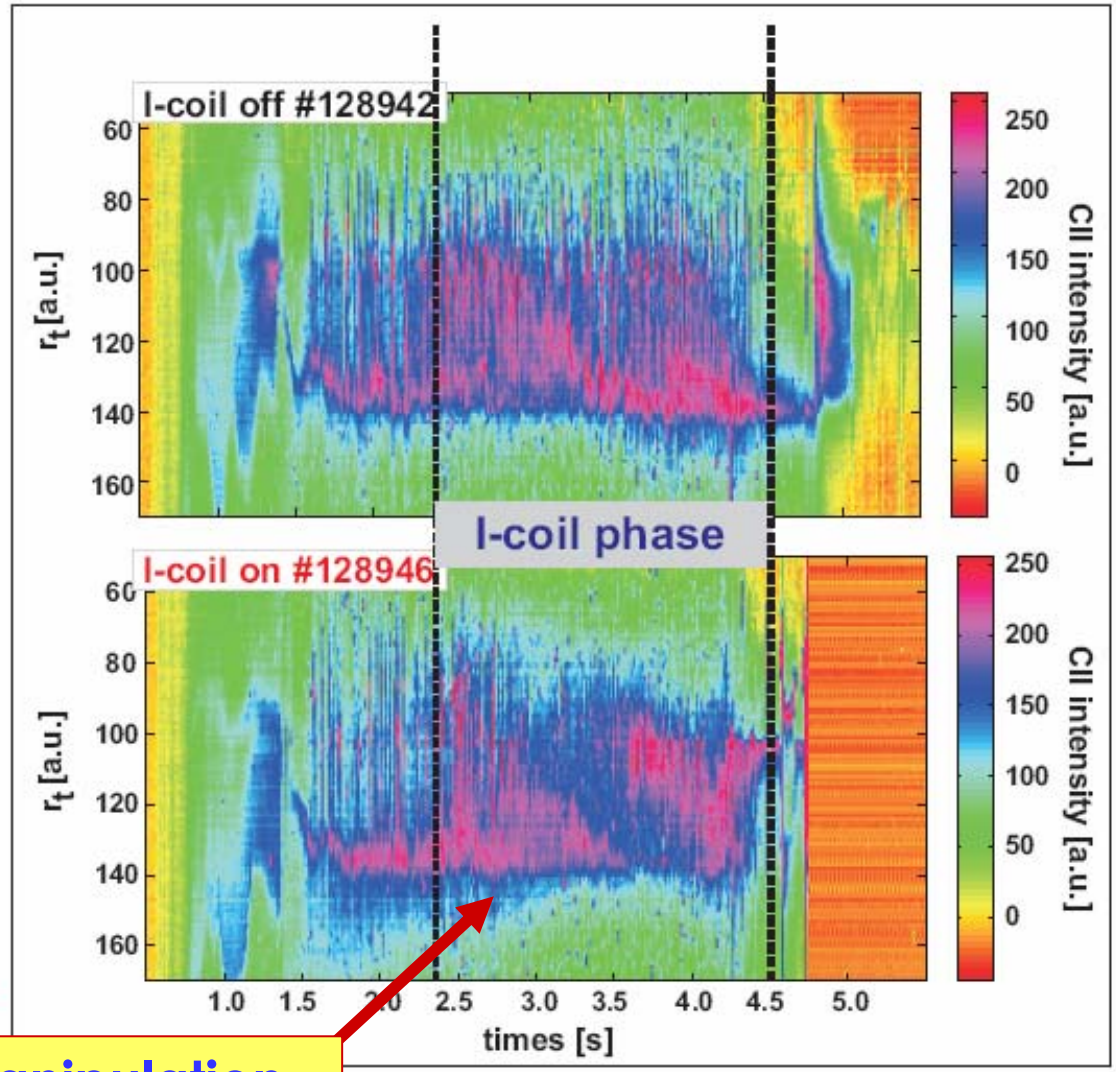
ELM frequency clearly rises



Good shot in n=1 -> I-coil + C-coil as EFC

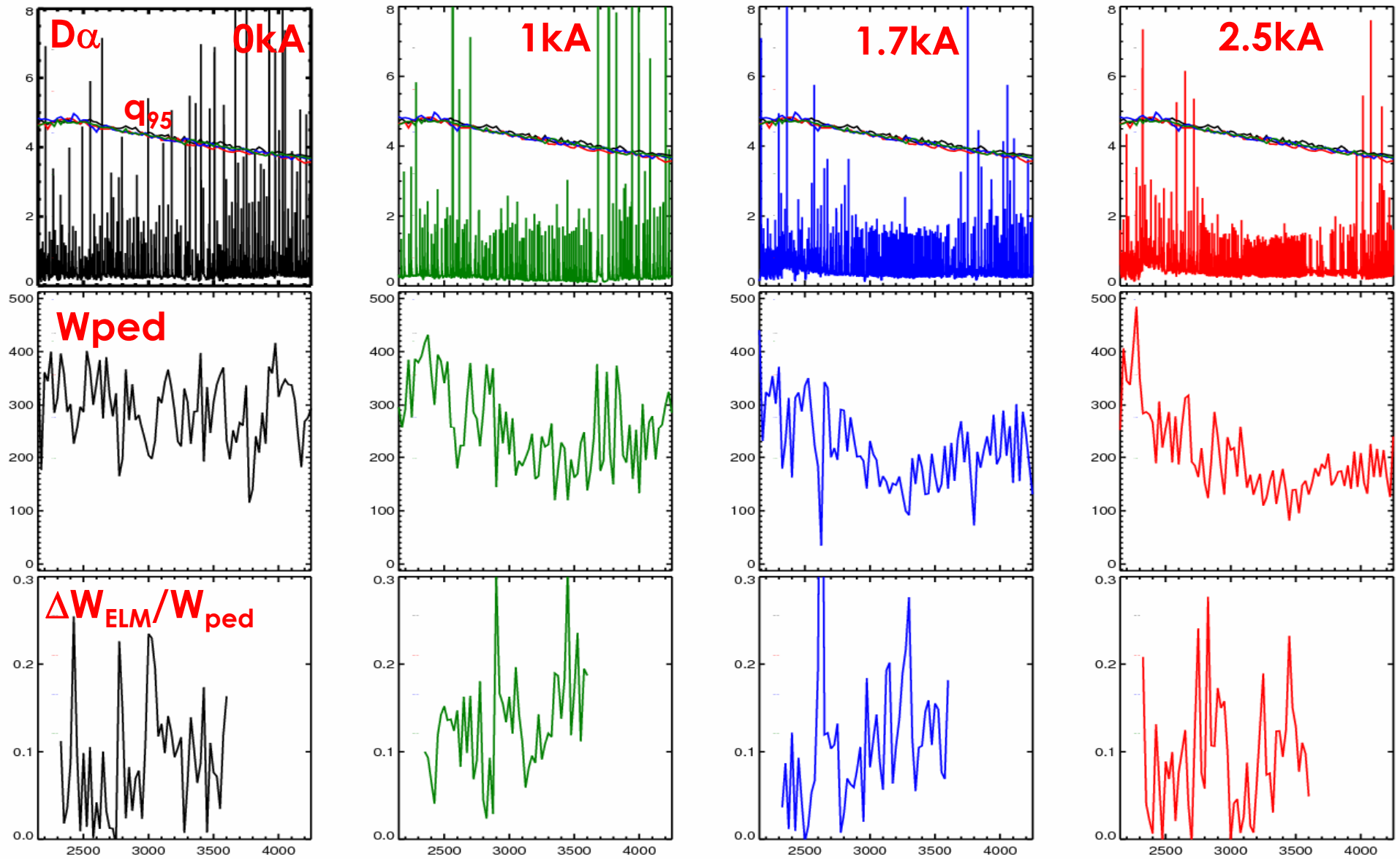
- #128942 and #128946
  - strike point manipulation is apperant
  - new "branch" appears -> related to tangles?





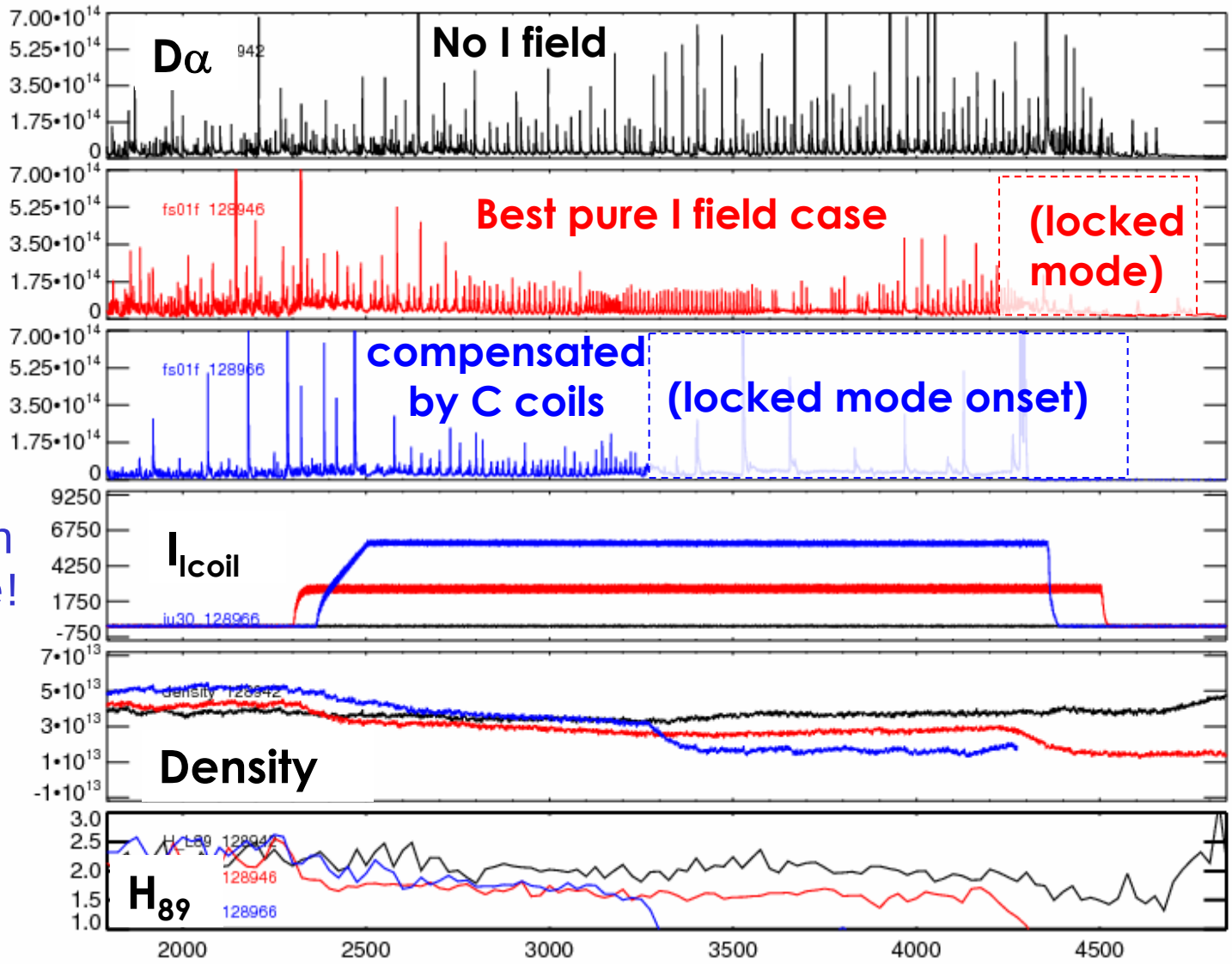
Strike manipulation but no splitting

ELM energy does fall, but in proportion to pedestal



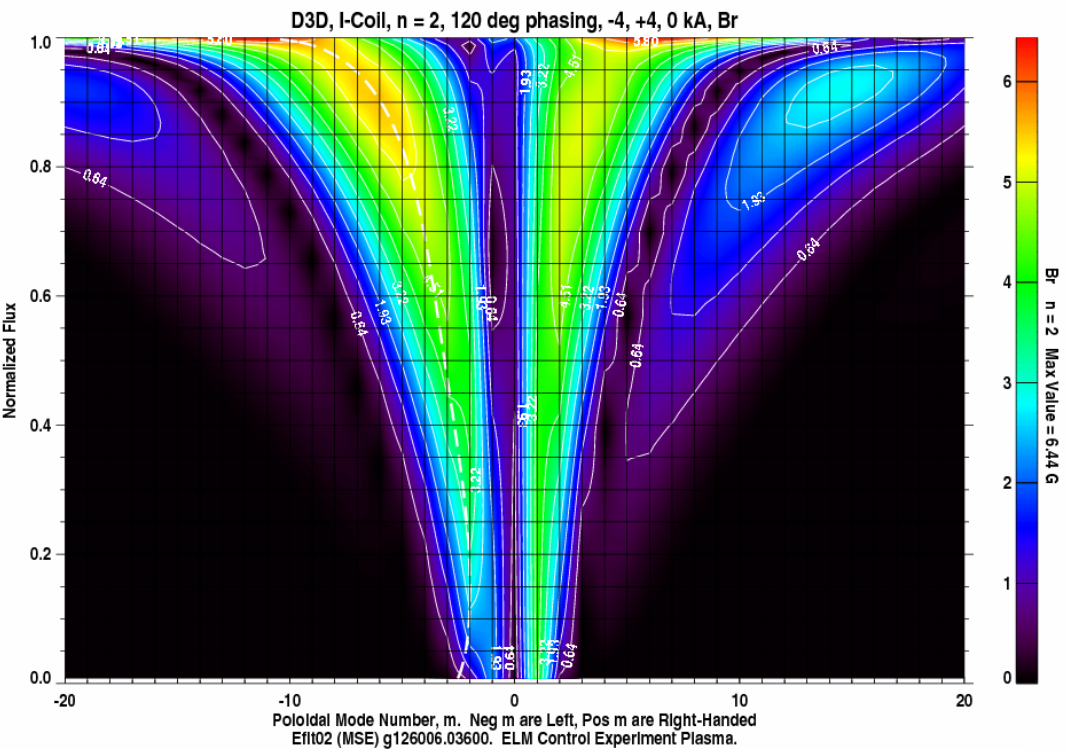
n=1 extended to higher amplitudes by removing core harmonics with C coils

- **Increased ELM frequency relative to reference**
- **But not more effective**
  - Error correction not that simple!
    - ***Eg this meeting!***
  - Locked mode is the problem

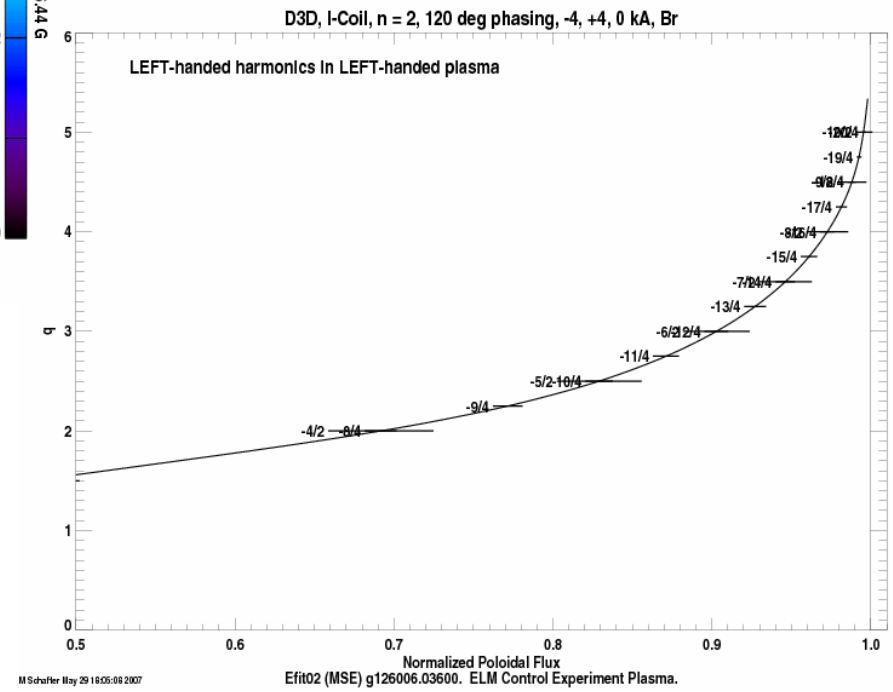


n=2 fields…

Modelling of n=2 fields also show promise…

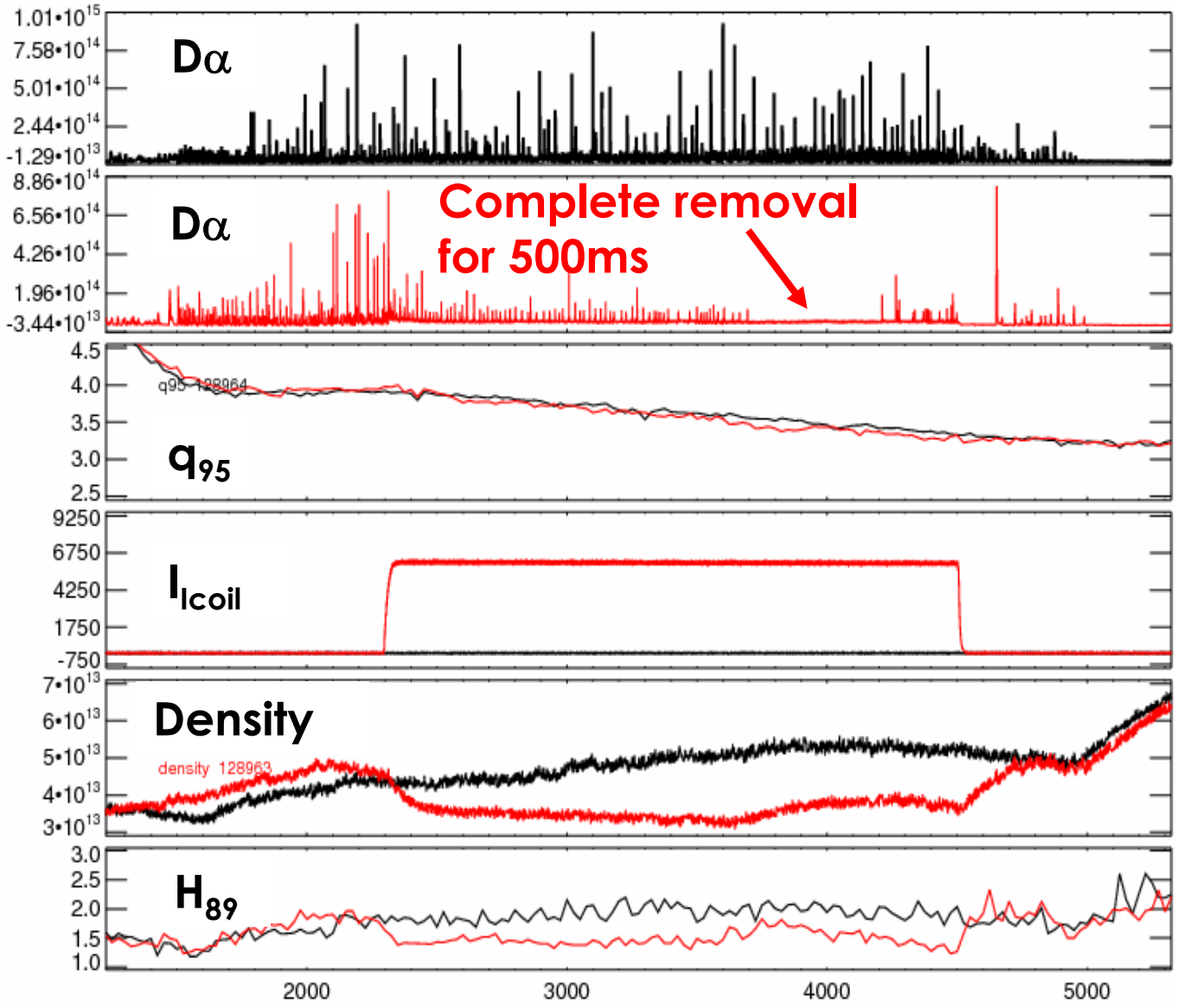


- **Better potential due to more islands!**



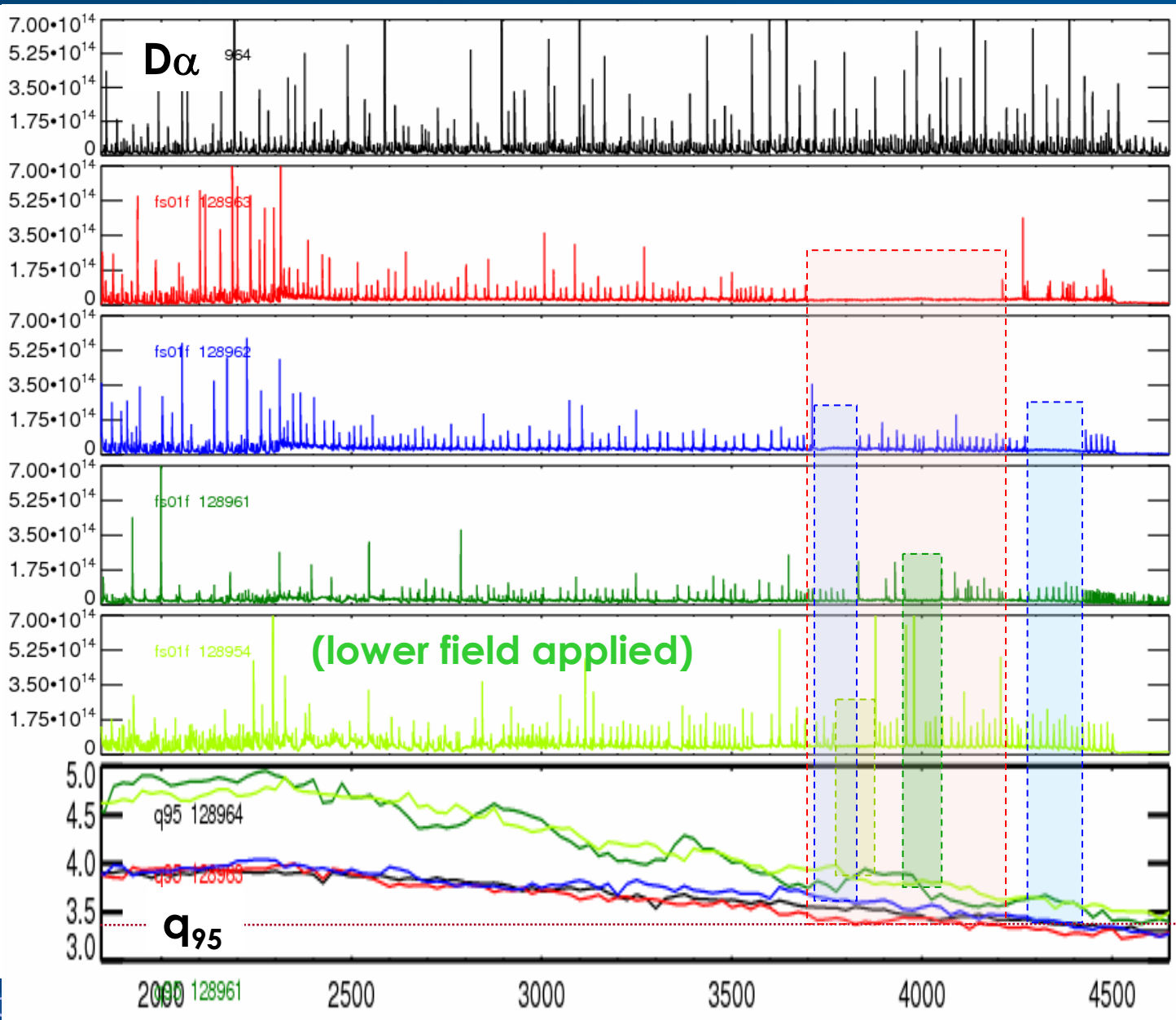
Promising new ELM suppression technique identified with n=2 fields

- Broad resonance at low q_{95}
- Clear density pump out effect
- But confinement fall
- ***Worthy of further exploration?***

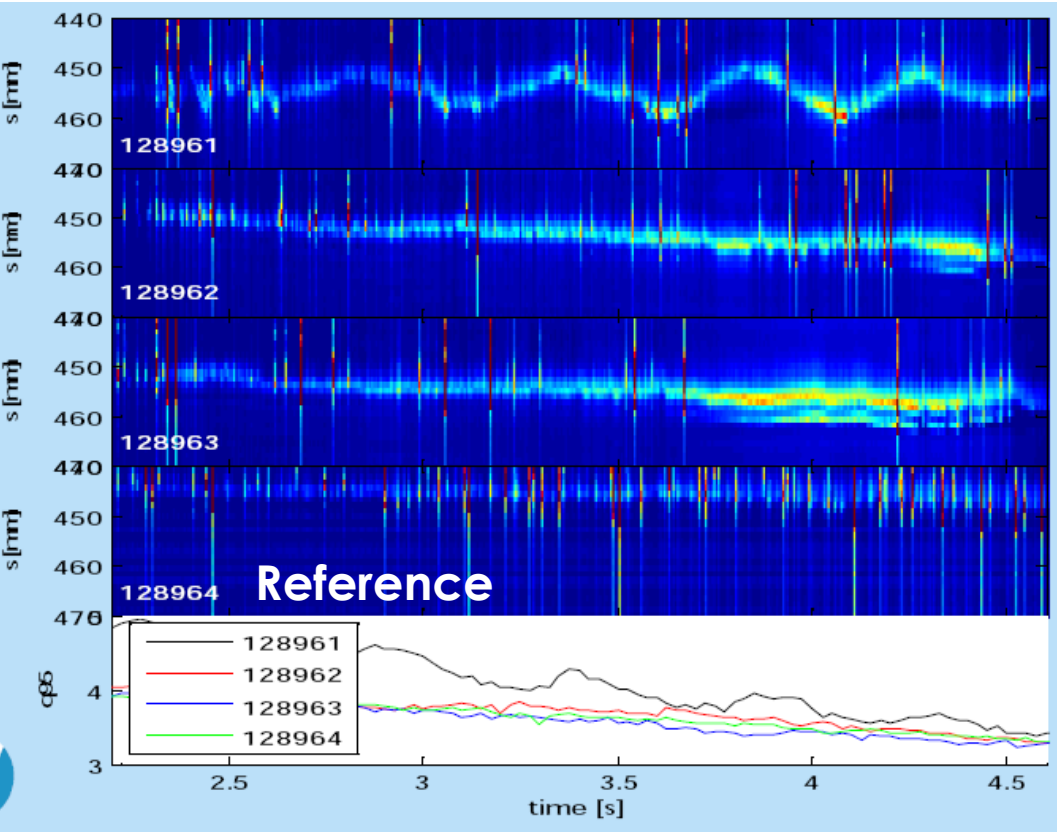


Comparison of resonant regions as q scans varied

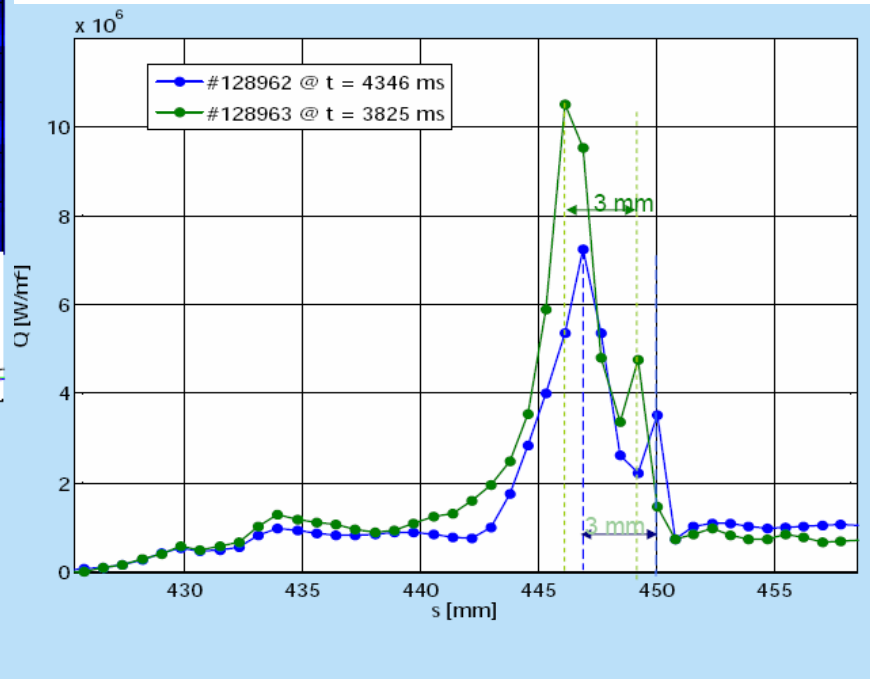
- **Best effect at q_{95}~3.4 (| |)**
- **Other (| | |) higher q 'resonances' less consistent**
- *Variation in L-H threshold need analysis*
  - ***impacting behaviour?***



IR shows possible effect of strike splitting

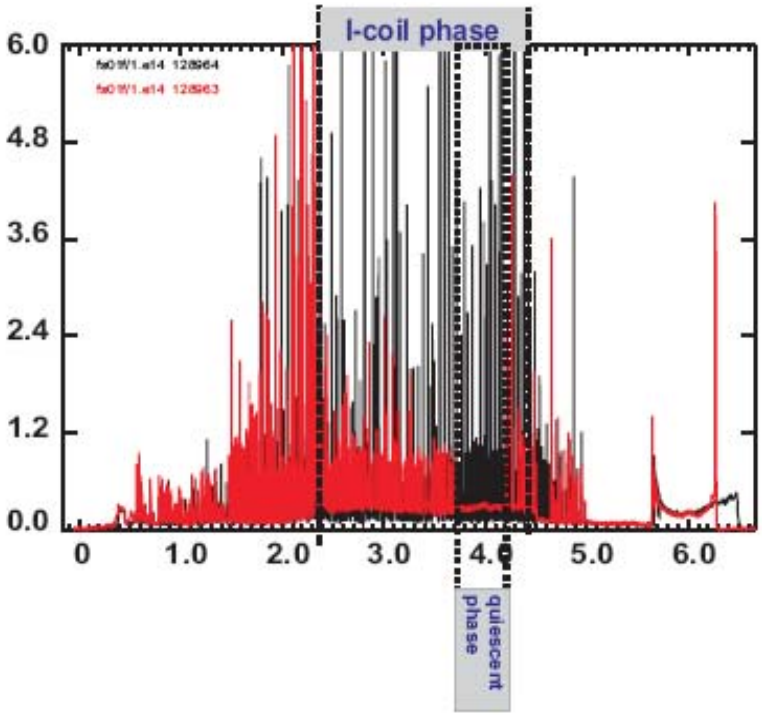


- **This signature often associated with edge ergodisation**
  - but visible camera shows strike broadening

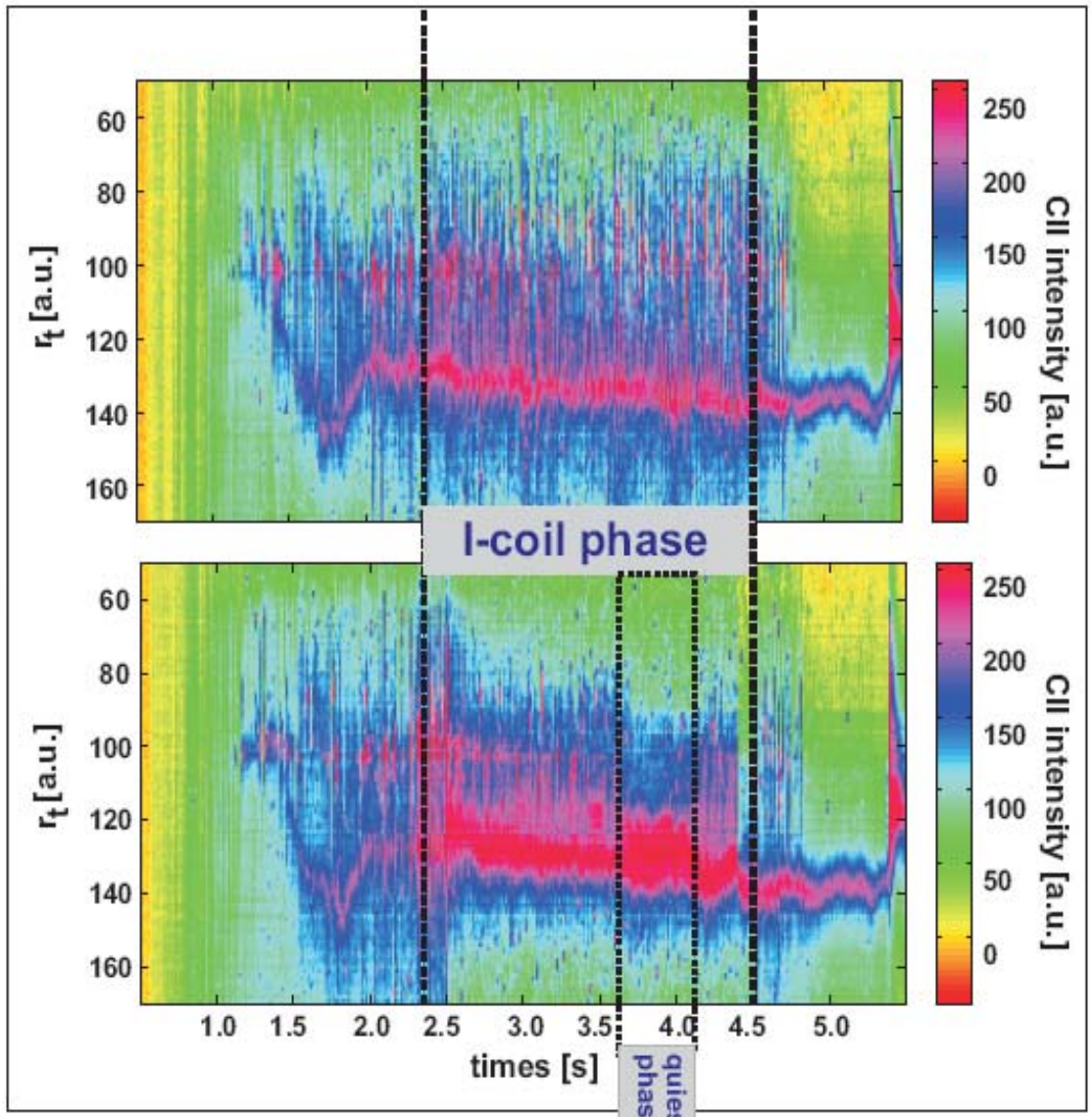


Good shot in n=2 -> I-coil with highest amplitude

- #128963 and #128964



- strike point broadening in quiescent phase
- no splitting observed, contrary to IR data from Marcin (but -> maybe not resolved))

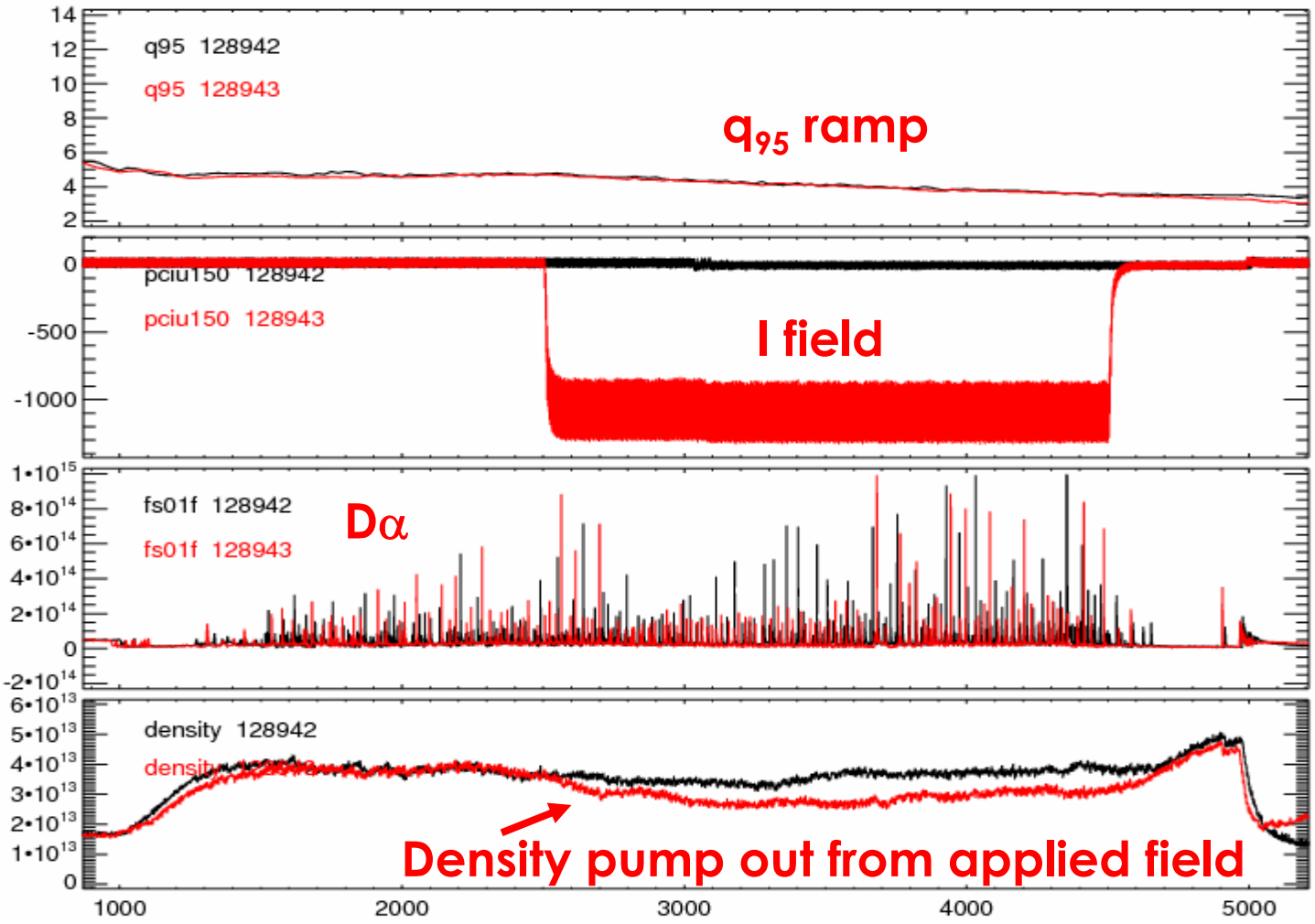


Conclusions

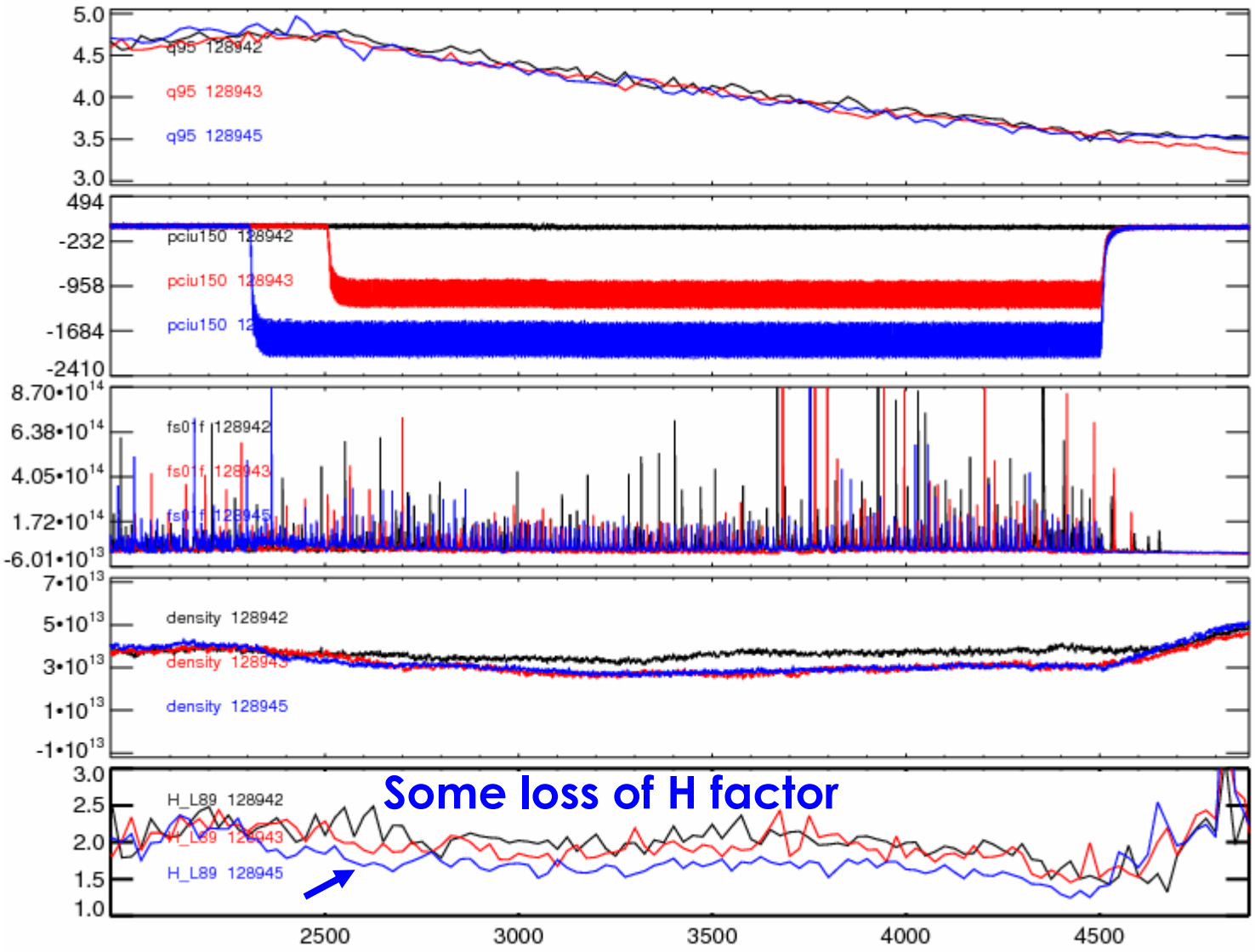
- **n=1 and n=2 fields can have significant effects on ELMs**
- **May offer potential for broader q_{95} resonance and more general applicability than n=3?** – works well on JET
- **But n=1 effect on DIII-D not as strong as JET & limited by locked modes…**
  - C-coil correction gives x2 improvement in LM threshold but demonstrates vacuum resonant model not whole story
  - Further check with "optimal" pure I coil phasing for ELMs & EF correction worth pursuing
- **Does n=1 on JET act through rotation change?**
- **DIII-D proof of principal n=2 complete suppression is a new world first, and needs to be explored further…***

**apologies for 'usual' hard sell line!*

First comparison pair shows an effect

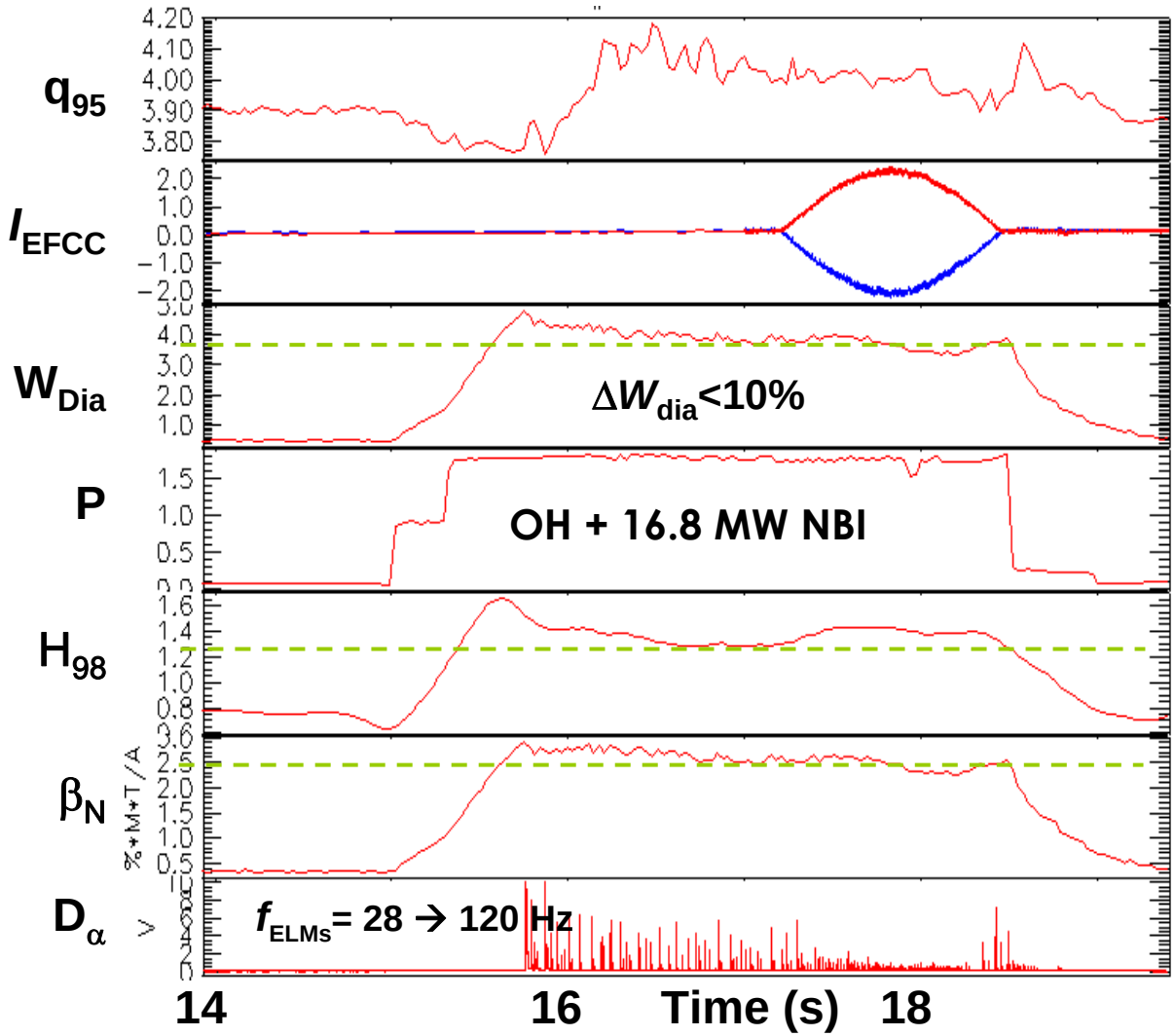


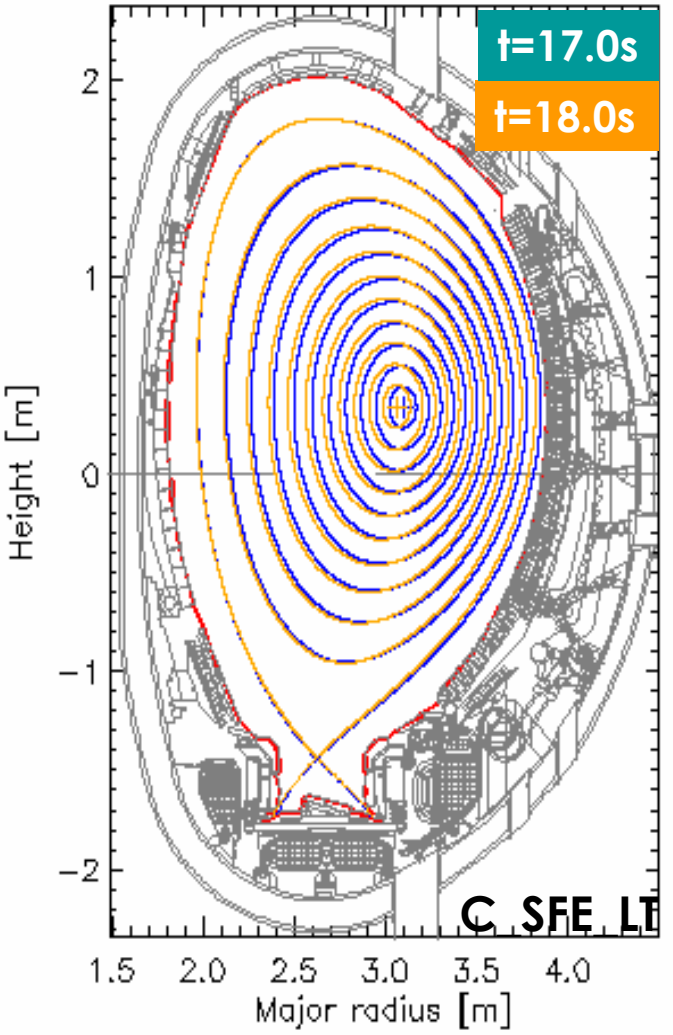
Larger fields progressively more effect



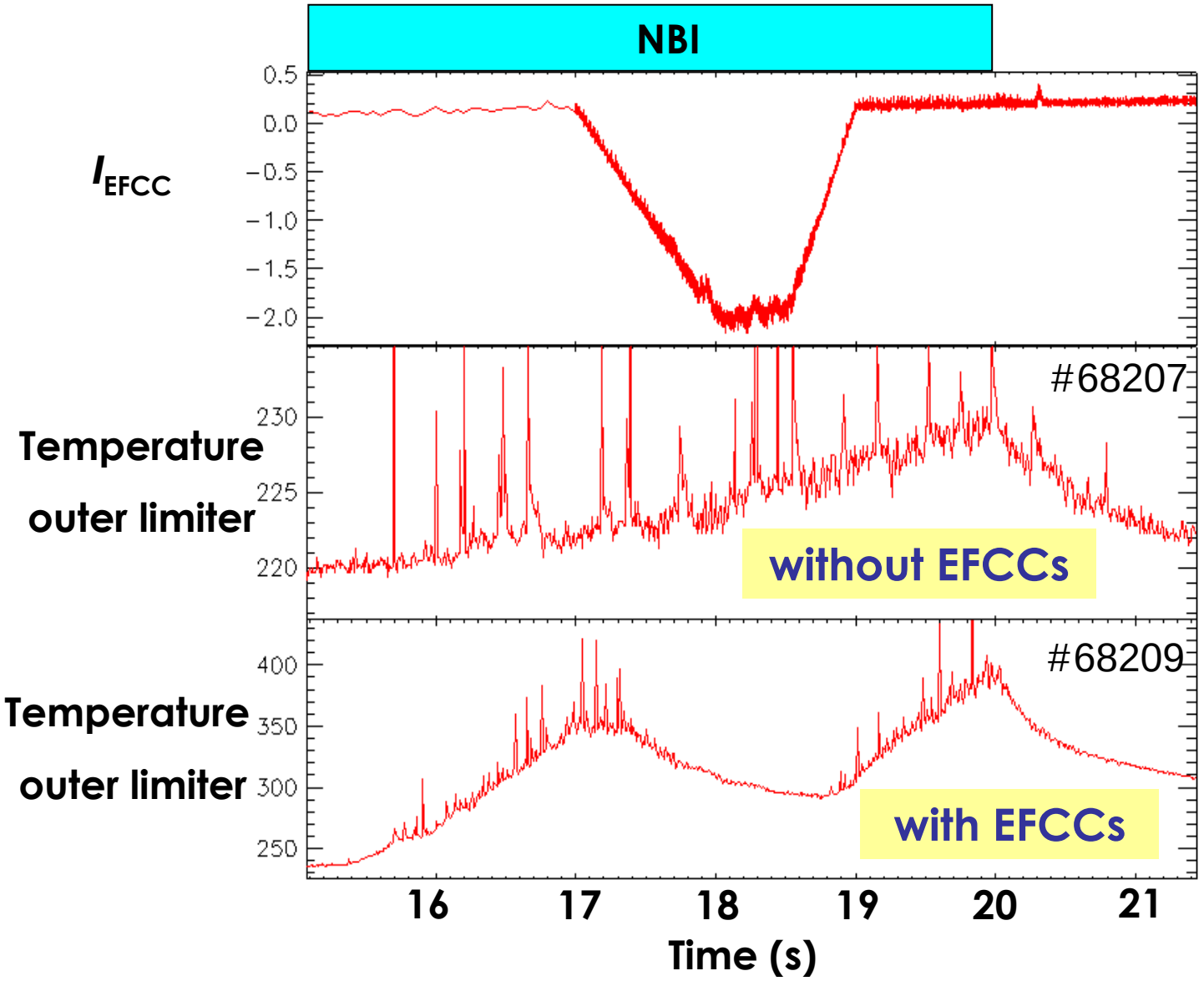
First tests of n=1 in low shape configuration

#67954; I_p = 1.6 MA; B_t = 1.84 T; q_{95} ~ 4.0; δ ~ 0.3





Reduced limiter heat loading



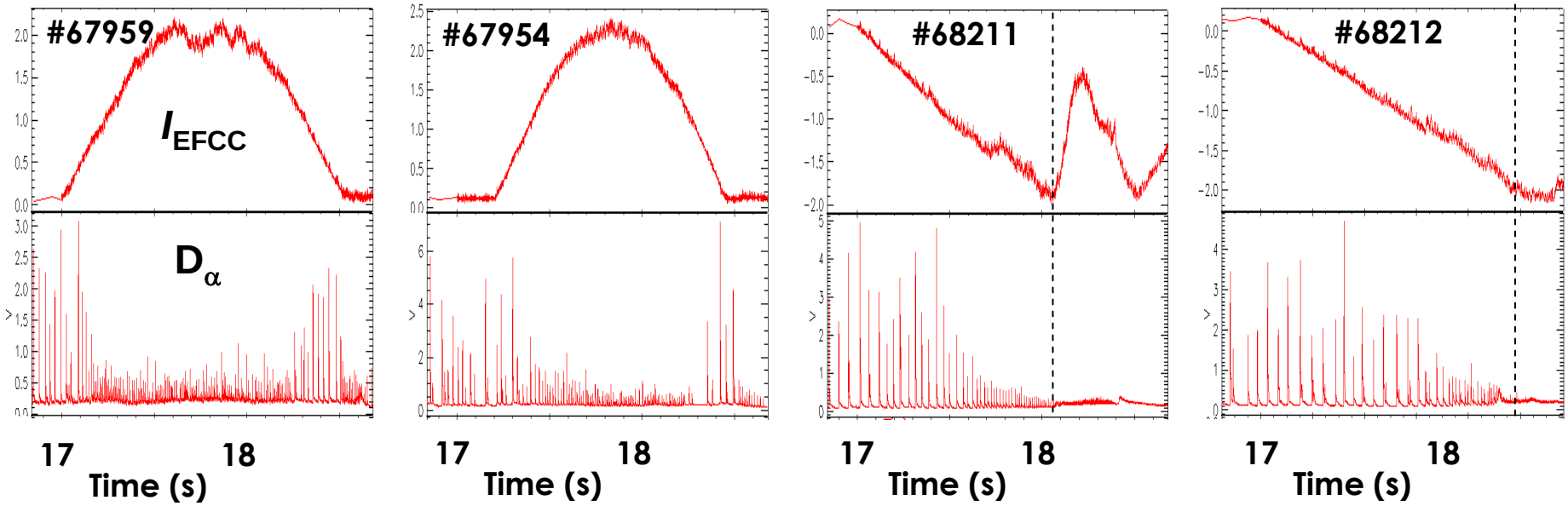
NBI: 9.5MW

NBI:16MW

q_{95} scan

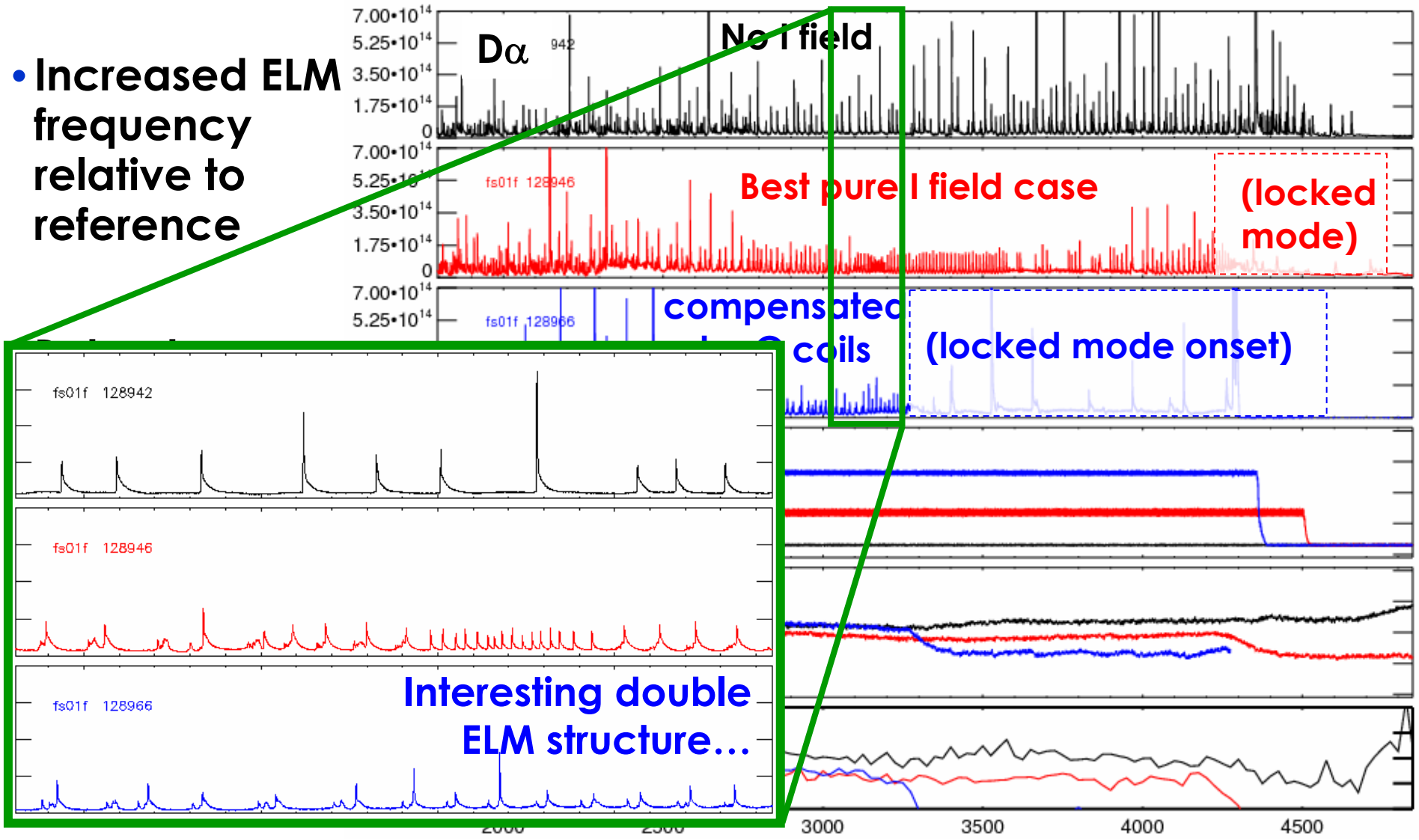
B_t=1.84 T; Plasma configuration: C_SFE_LT

I_p=1.4MA	I_p=1.6MA	I_p=1.8MA	I_p=2.0MA
q_{95}=4.8	q_{95}=4.0	q_{95}=3.5	q_{95}=3.0



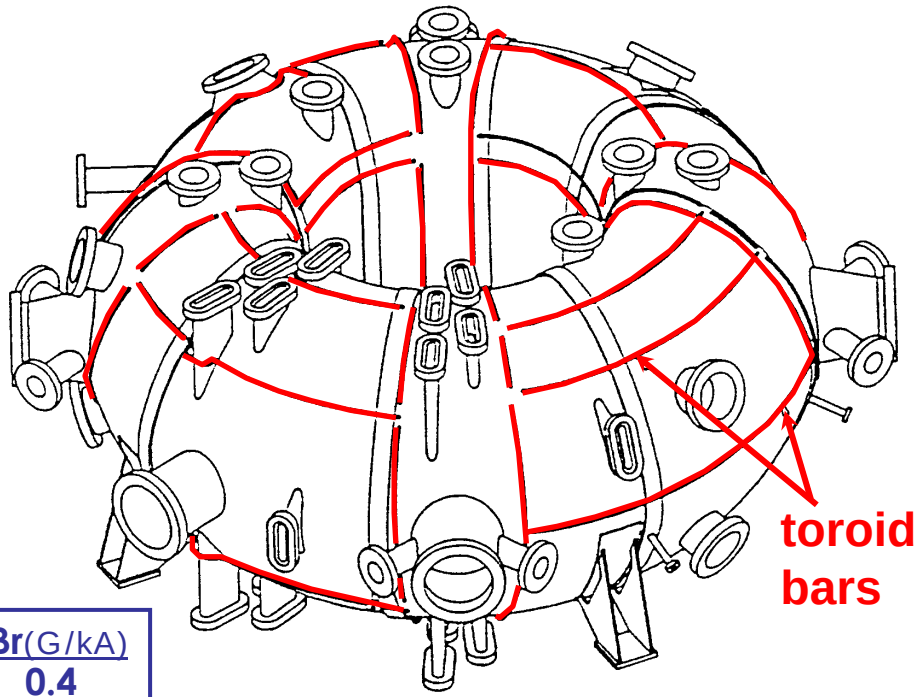
n=1 extended to higher amplitudes by removing core harmonics with C coils

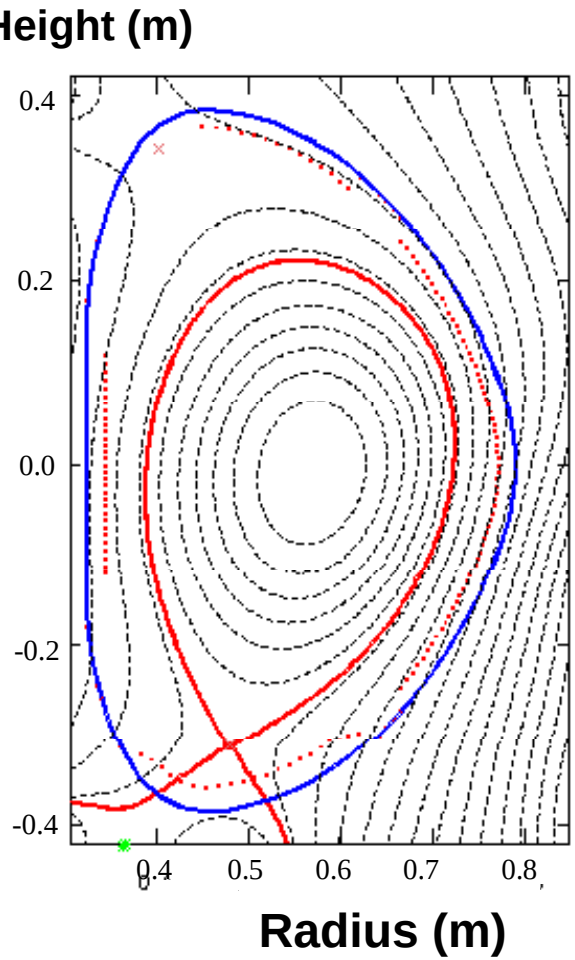
- Increased ELM frequency relative to reference



COMPASS-D RMPs configuration

- **2000 configurations possible in each quadrant:**



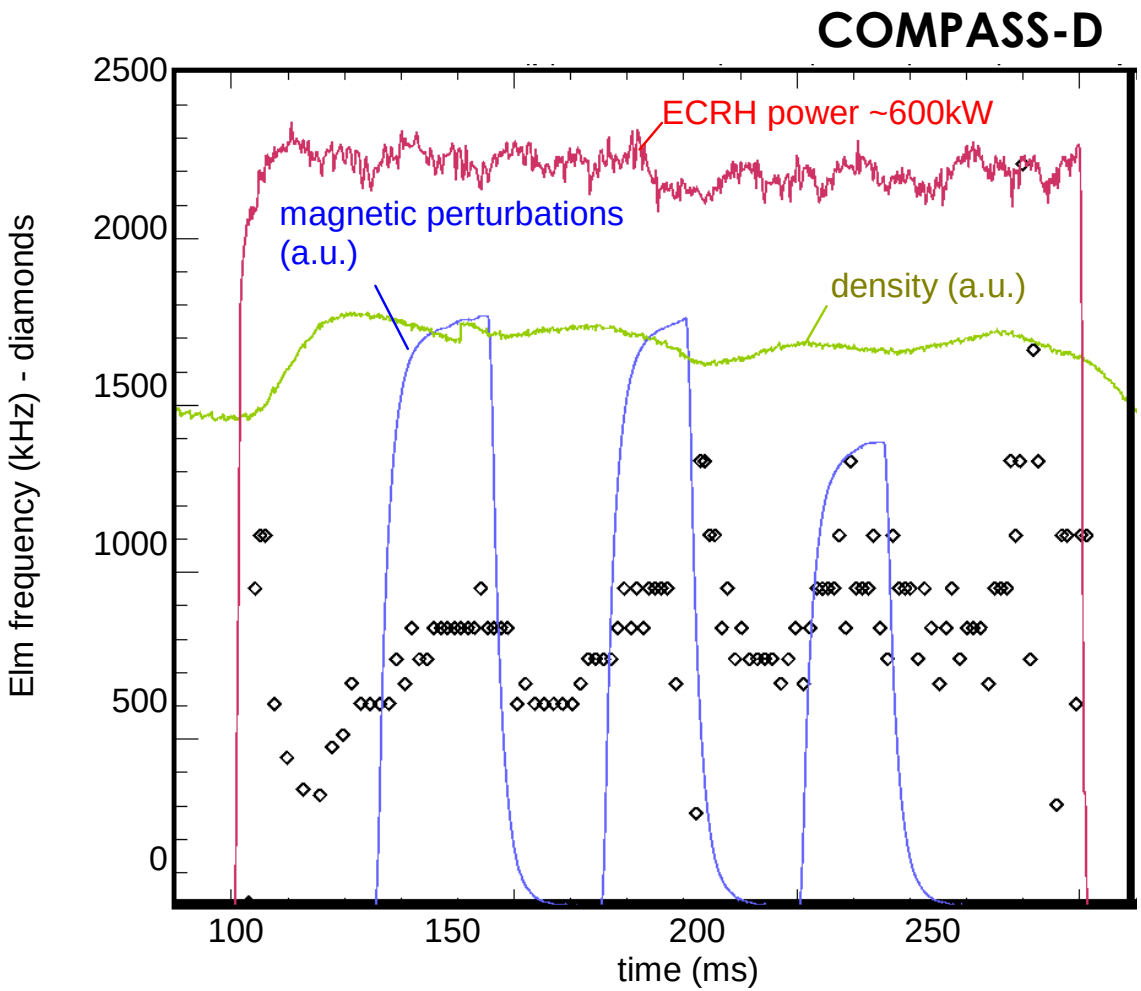


m/n	Br(G/kA)
6/1	0.4
5/1	1.0
4/1	1.5
3/1	1.2
2/1	0.2
1/1	1.7

➢Choose optimal 4/1 & 5/1 at q=2 surface

Type III ELM control in COMPASS-D

- No 2/1island formed
- 10% fall in stored energy with RMP
- Larger fields led to H-L
- Possible evidence for a threshold in required current



Influence in ELM-free H-mode in COMPASS-D