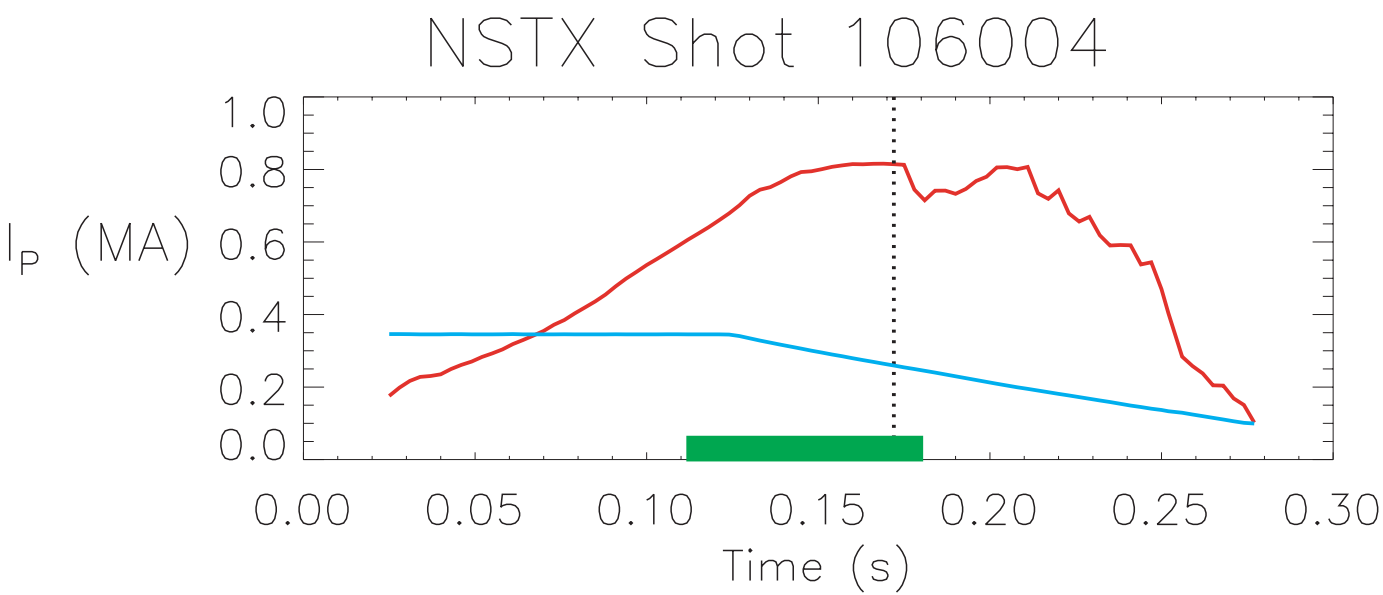
Modeling Kink Instabilities in NSTX

J. Manickam, E. Fredrickson,
M. Okabayashi and the NSTX team

Experiment to drive an External Kink



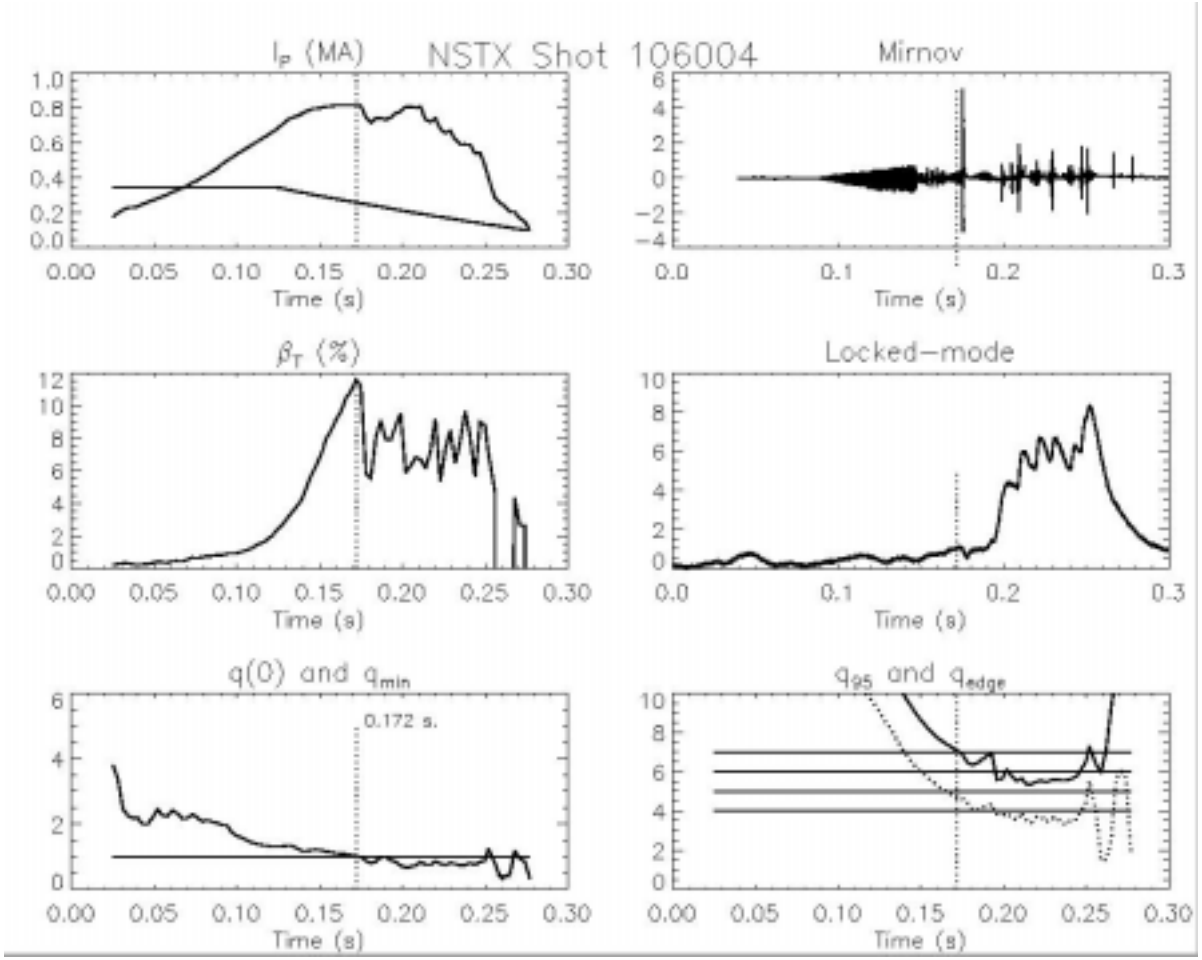
- Ramp current to maintain finite edge current density and drive the external kink
- Ramp down B-tor to reduce q_95
- Early beam heating to keep q_min > 1

Signature of the edge current driven ideal kink

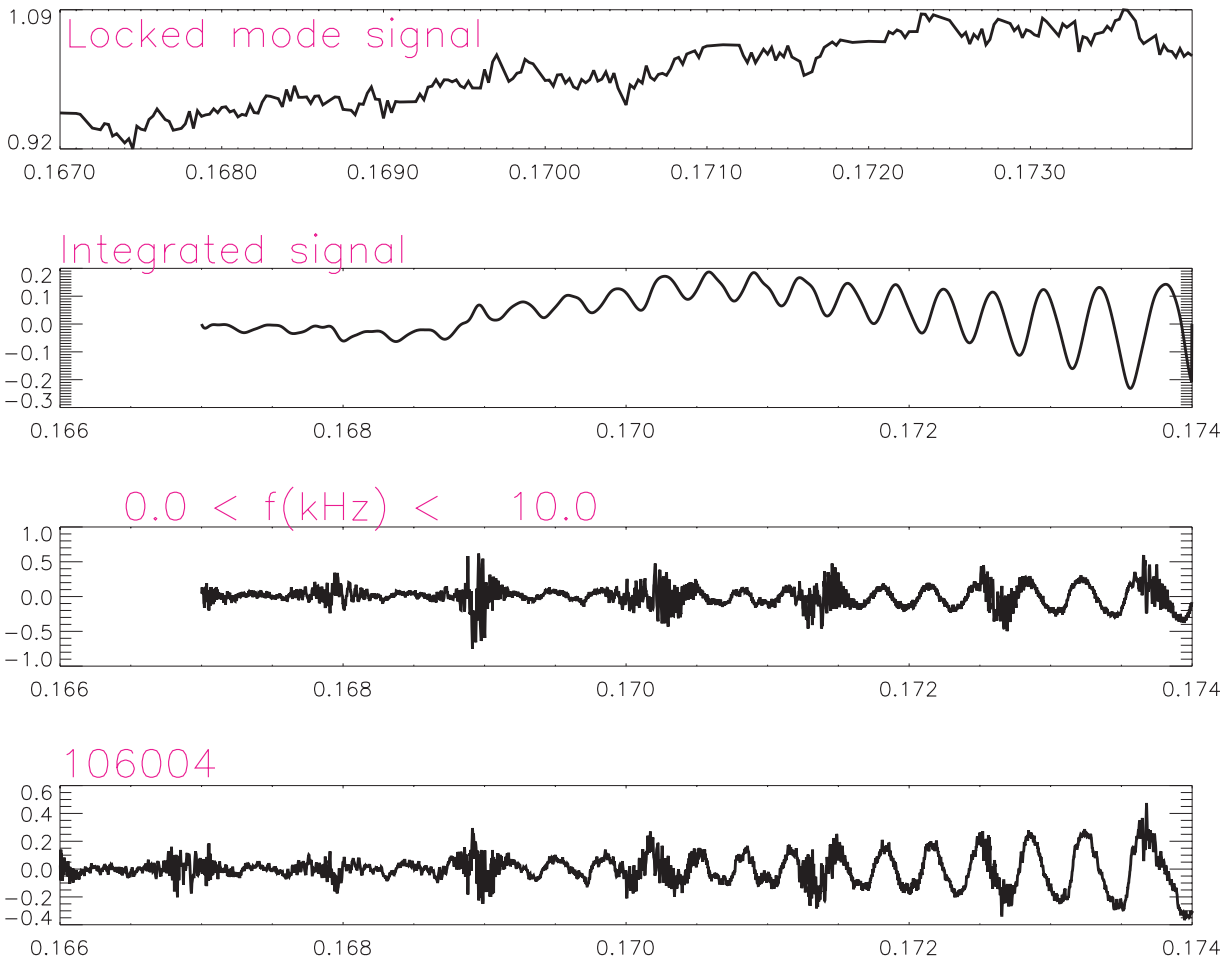
MHD event associated with

- A large perturbation at plasma edge
  - Small or no perturbation in core
  - Low frequency non-axisymmetric mode
- Correlation with q_95
- No island structure on SXR contours
- Mode frequency not locked to plasma
- Parametric dependence

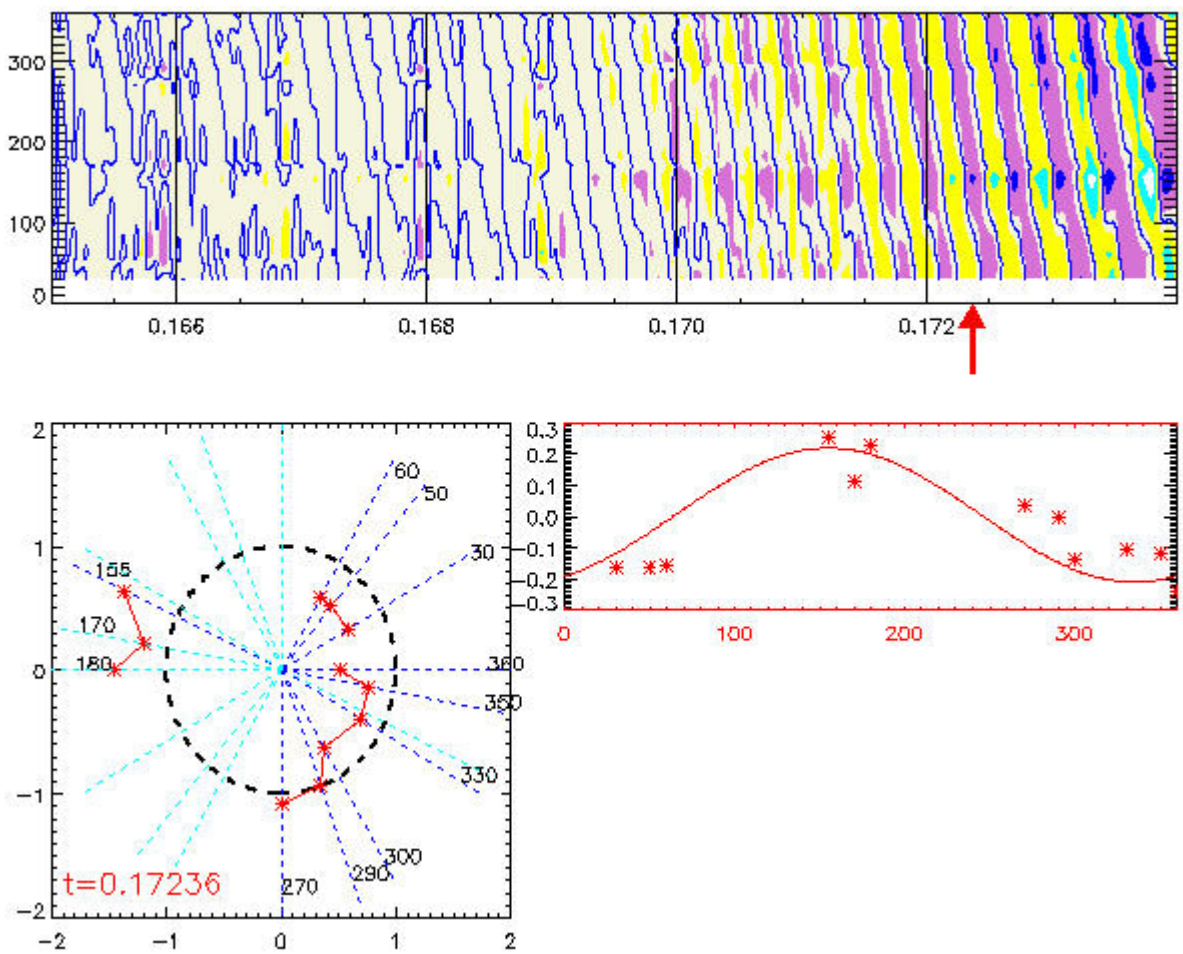
Experimental observation of a current driven kink



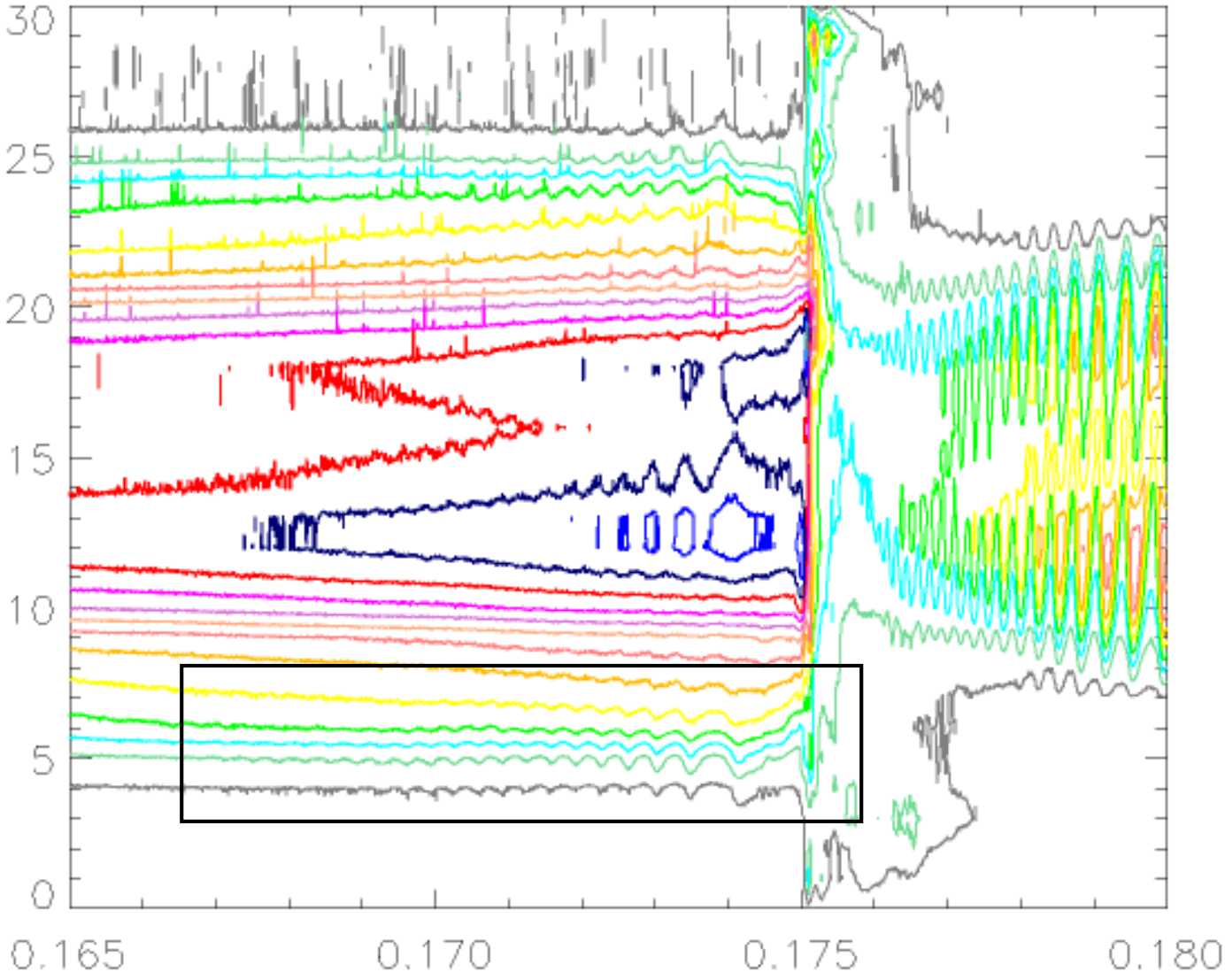
Mirnov signals show a distinct growing mode



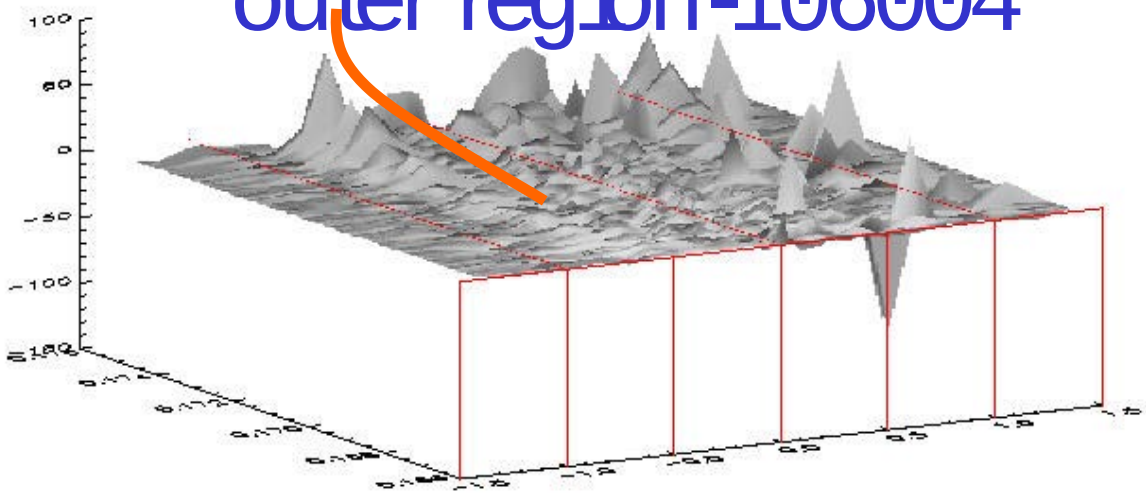
n=1 mode inferred from phase analysis

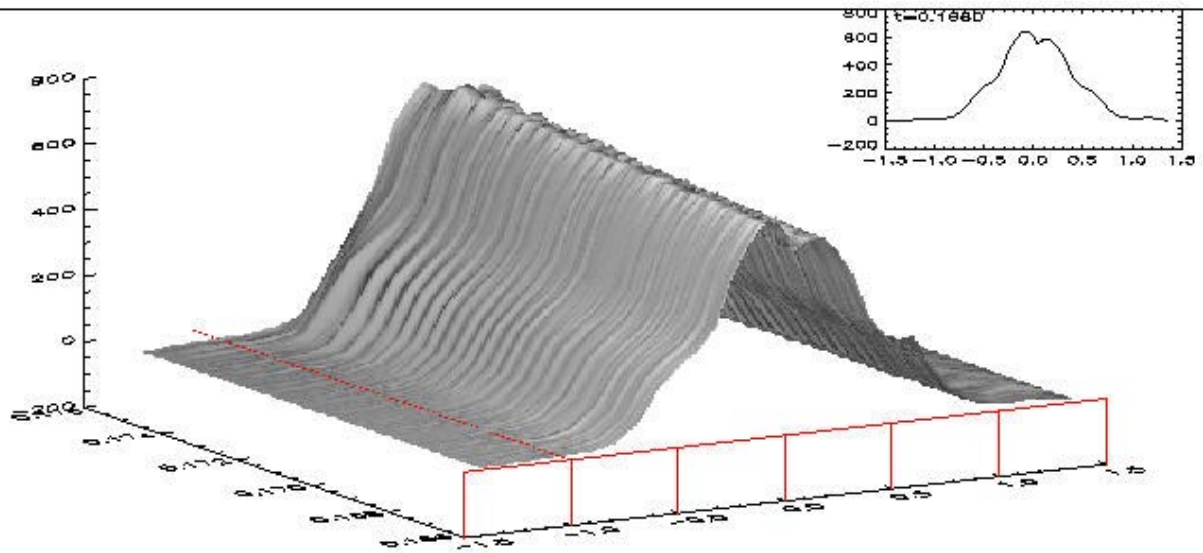


106004 – USXR signal shows no island structure



A growing perturbation is seen in the outer region-106004

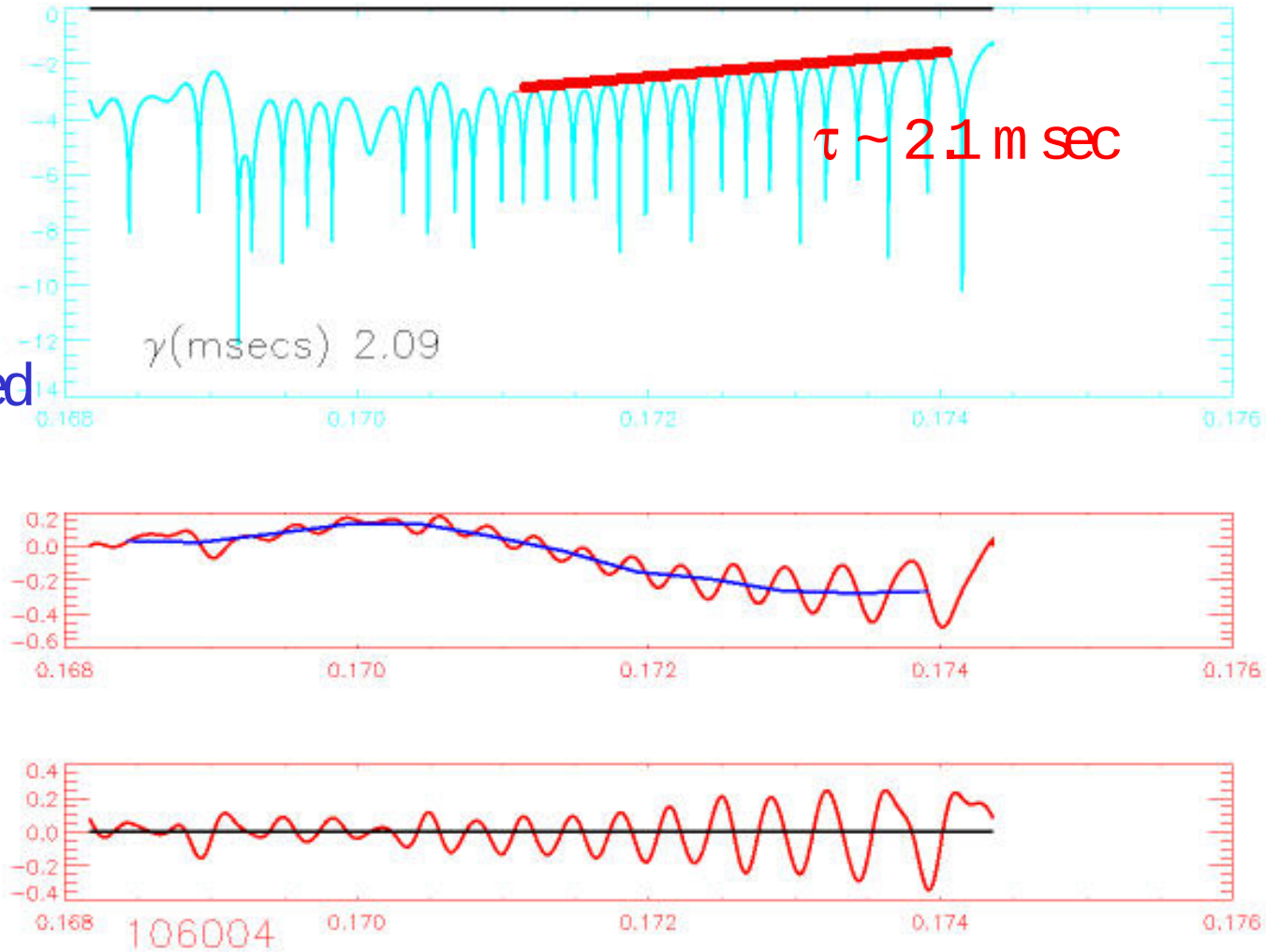




Growth-rate is determined

integrated

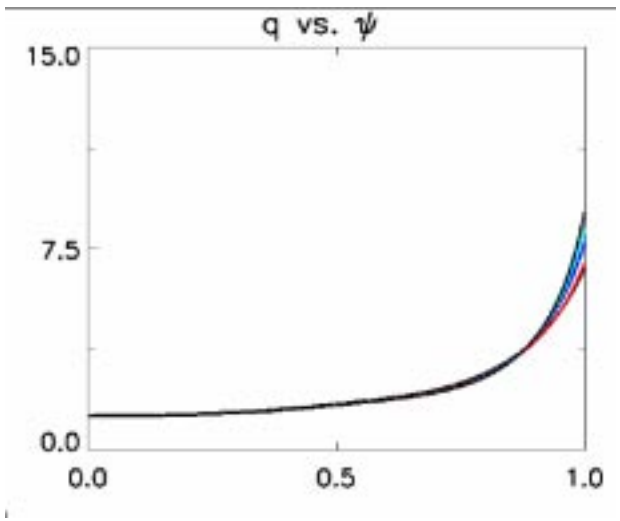
filtered

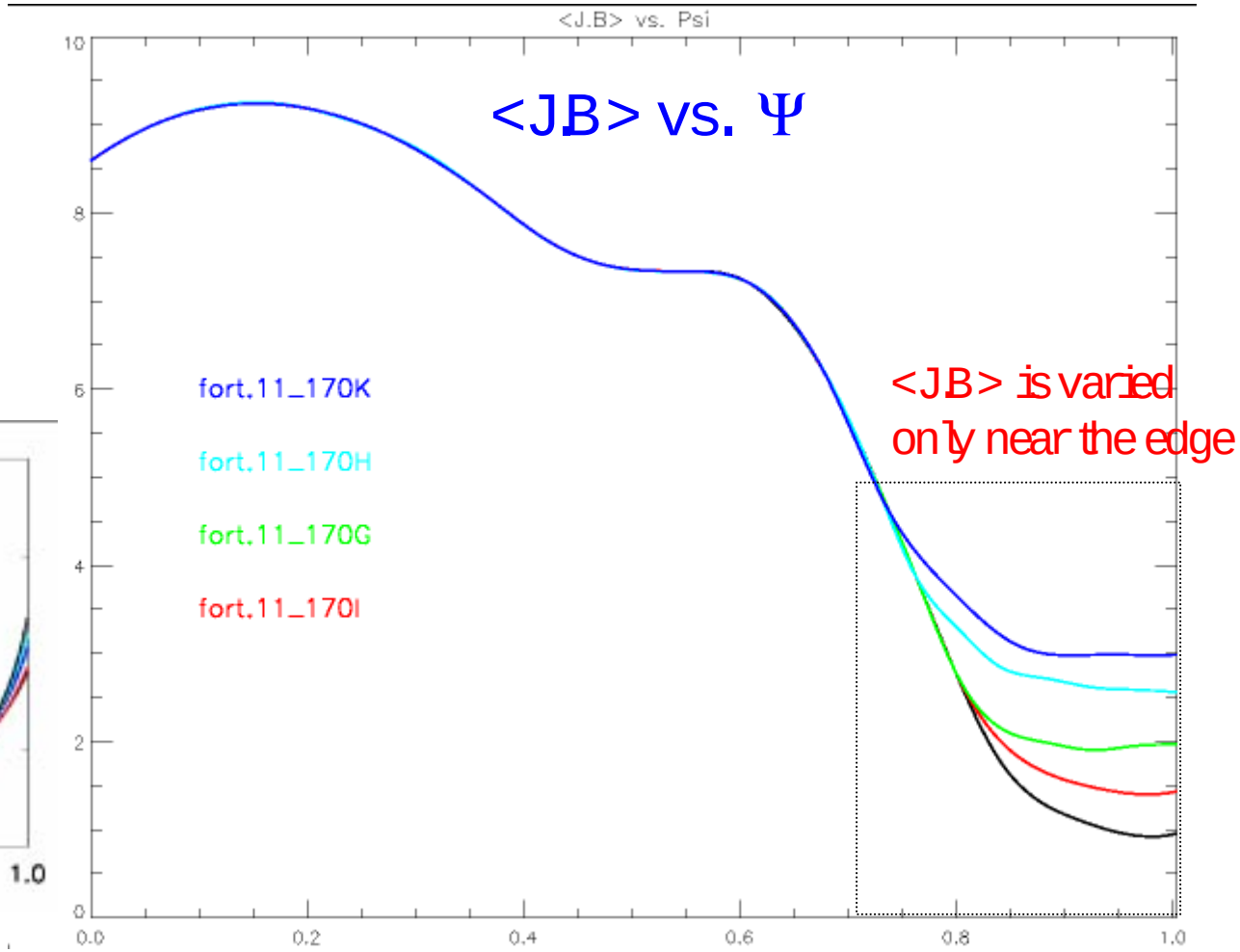


Theoretical modeling

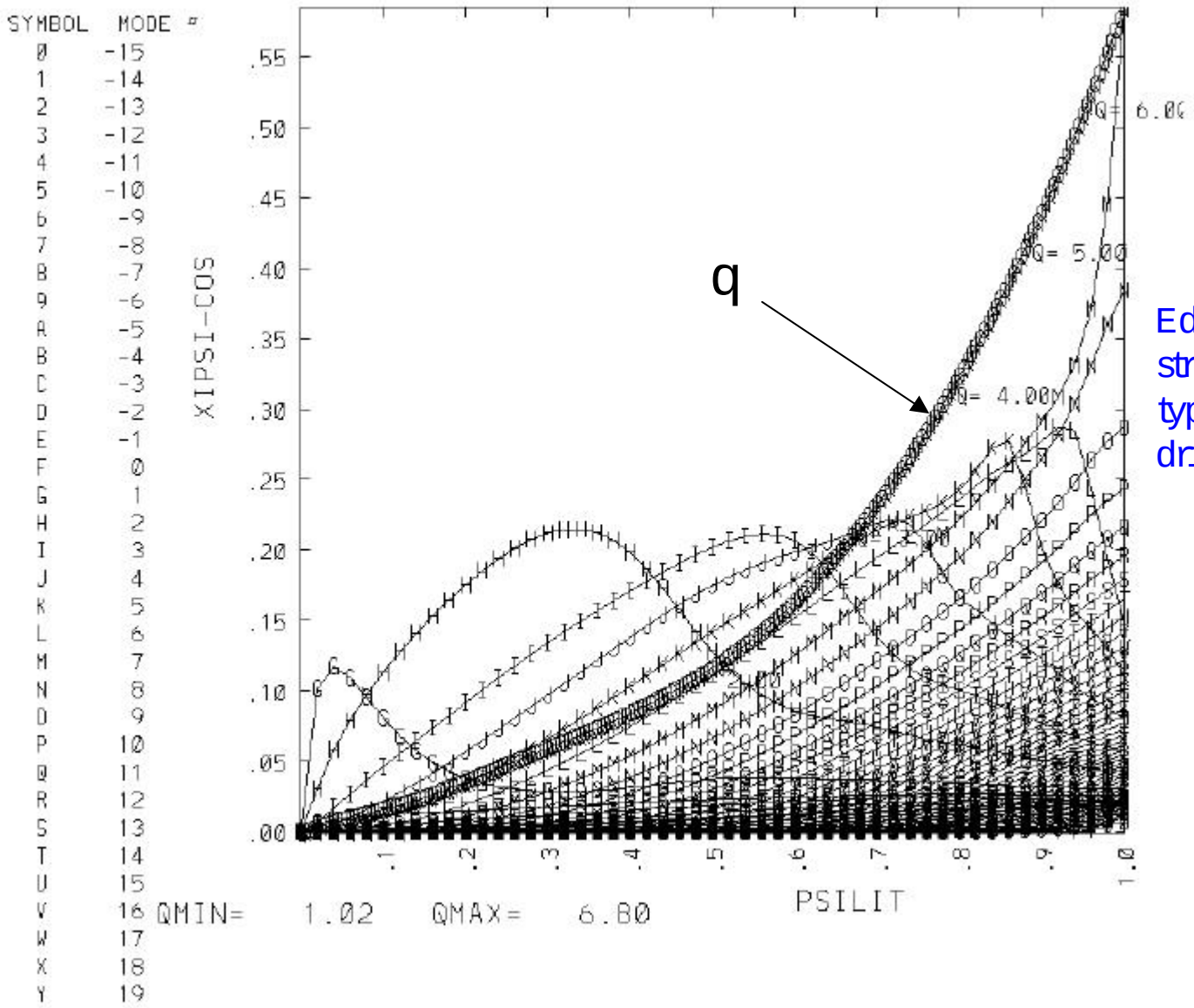
- EFIT
  - model pressure profile
  - current profile, ff', adjusted to match magnetics
  - shape determined self-consistently
- TRANSP
  - uses EFIT shape and q-profile
  - kinetic pressure
- No MSE data to guide q-profile constraint

Model current profiles based on 106004



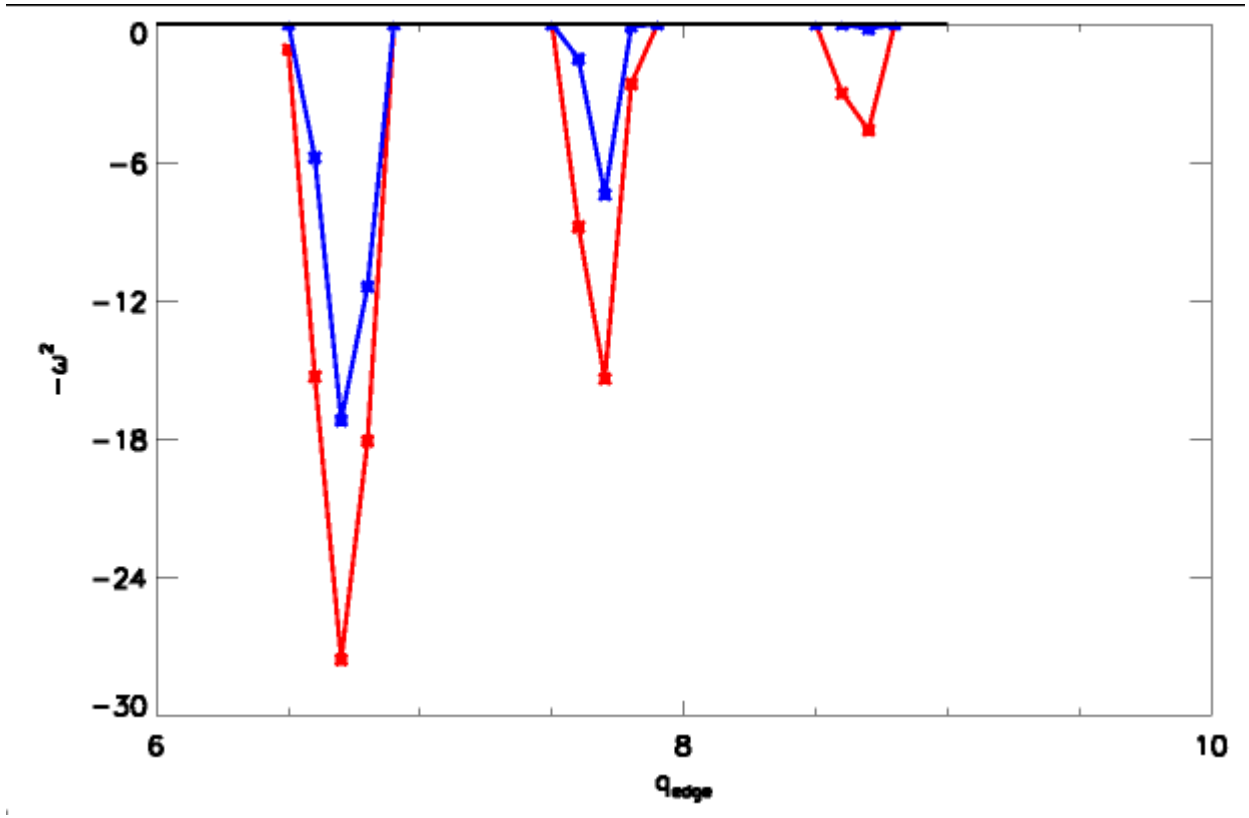


External kink mode structure

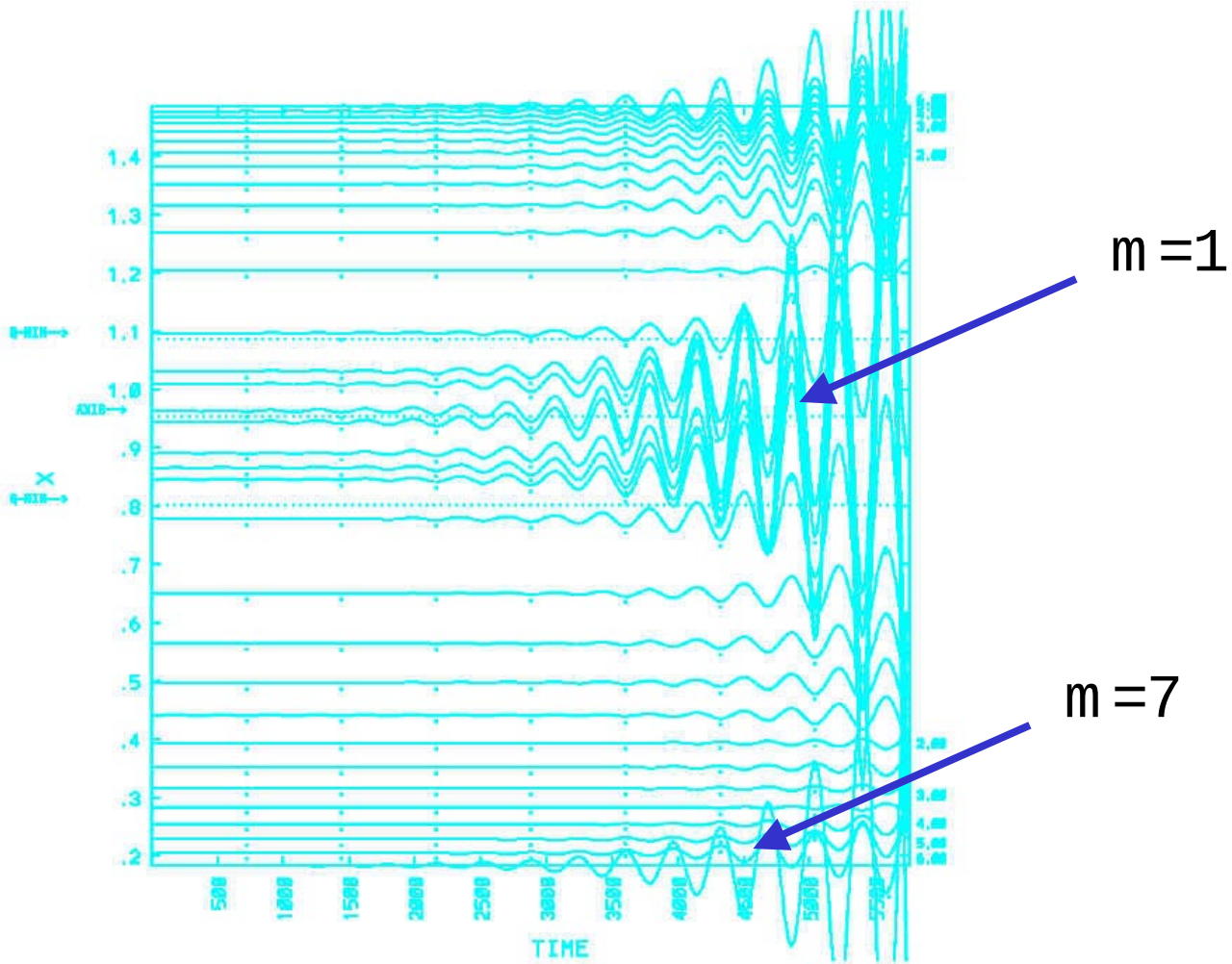


Edge dominant mode structure typical of a current driven kink

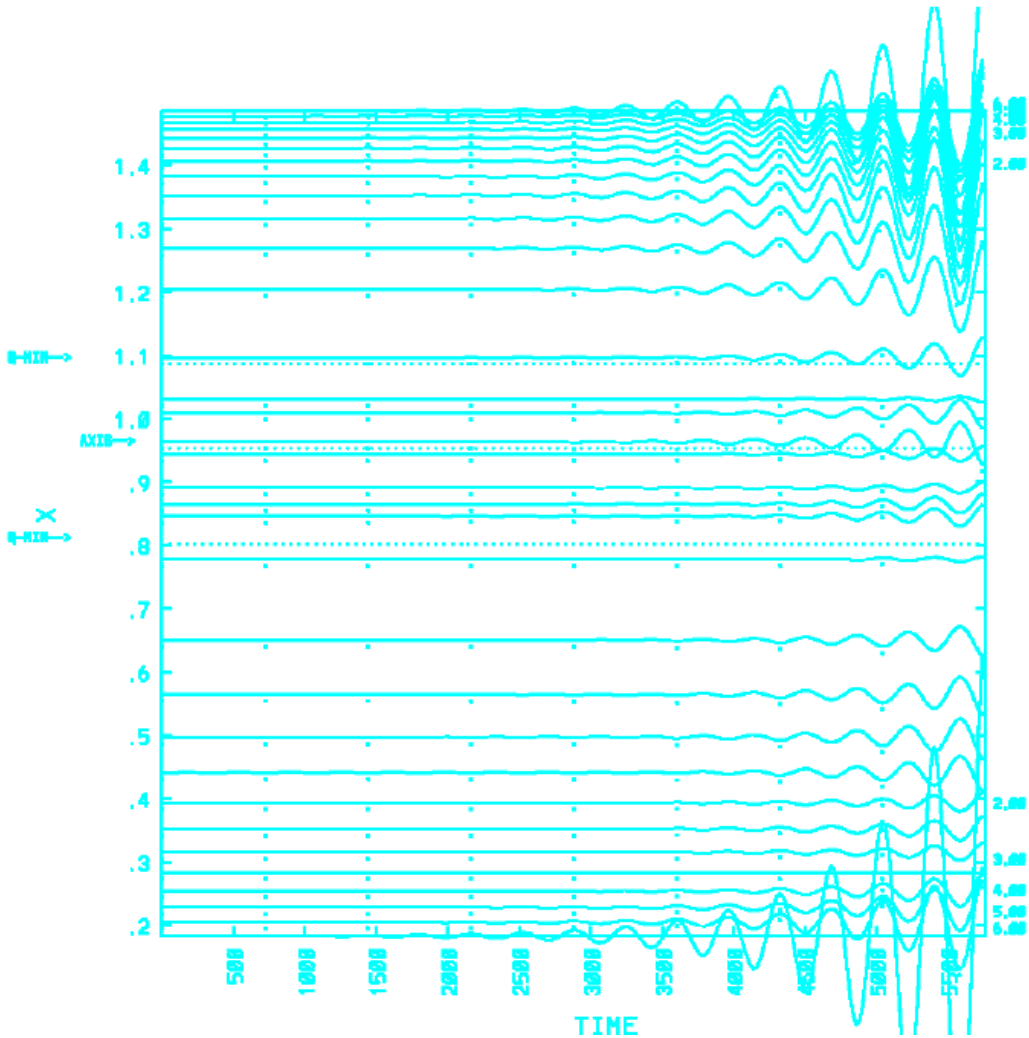
Growth-rate shows the classic dependence on q_{edge} for the external kink



Simulation of ECE signal for 106004



Simulation of ECE signal for 106004 suppressing the m=1 component



Growth-rate estimates of theory and experiment are similar

To compare the growth-rate we must account for the equilibrium evolution.

Using the Chance-Callen formula:

$$\tau \sim (3/2)^{2/3} (\gamma_{MHD})^{-2/3} (\gamma_H)^{-1/3}$$

$\gamma_{MHD} = 0.067 (\text{msec})^{-1}$ $\gamma_H = 28 (\text{msec})^{-1}$

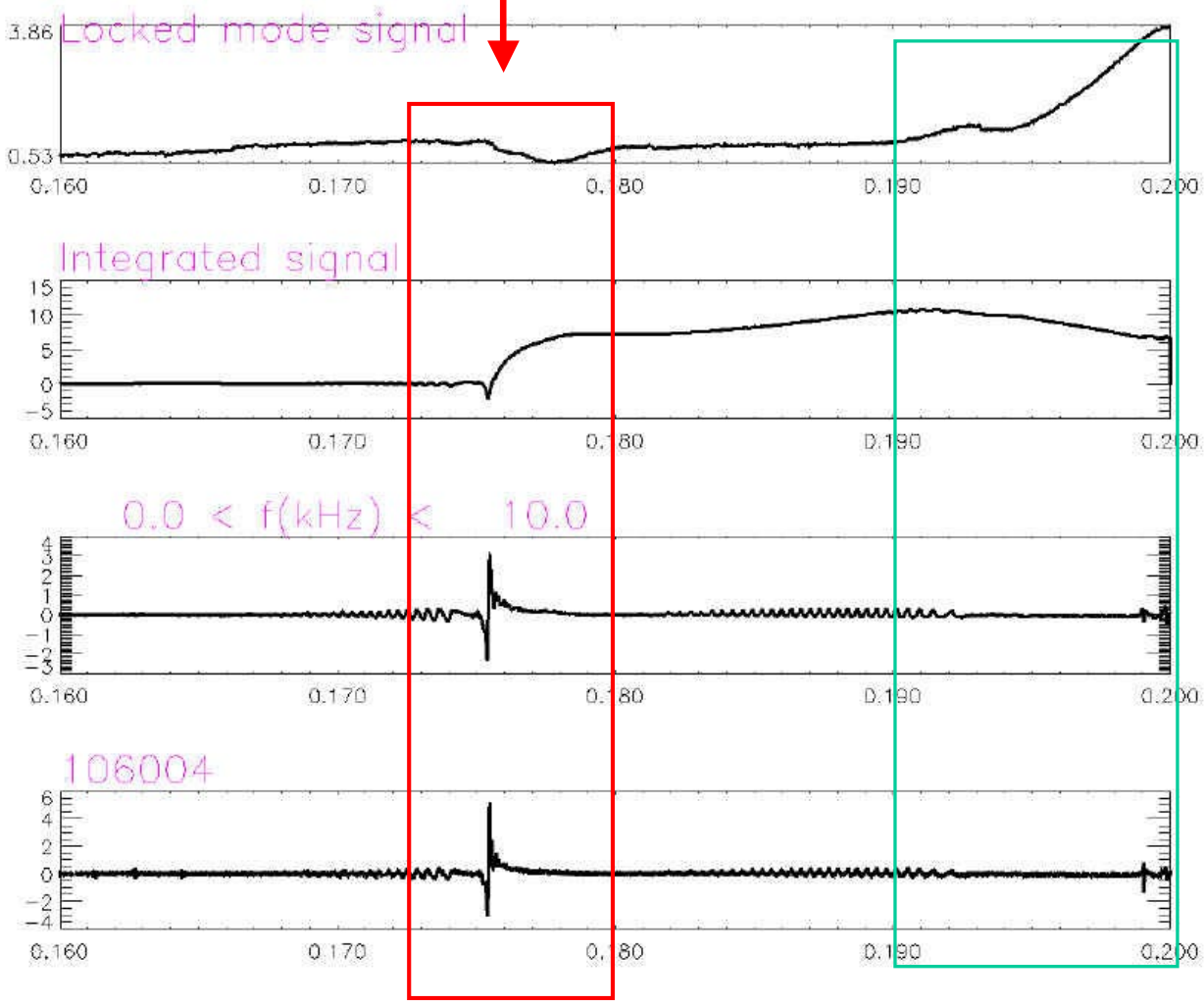
$$\tau = 2.5 \text{ msec}$$

The experimental growth time was estimated to be $\tau = 2.1$ msec

We might expect that as the mode grows its rotation slows down as it couples to the external walls or error fields and a locked mode starts to grow –

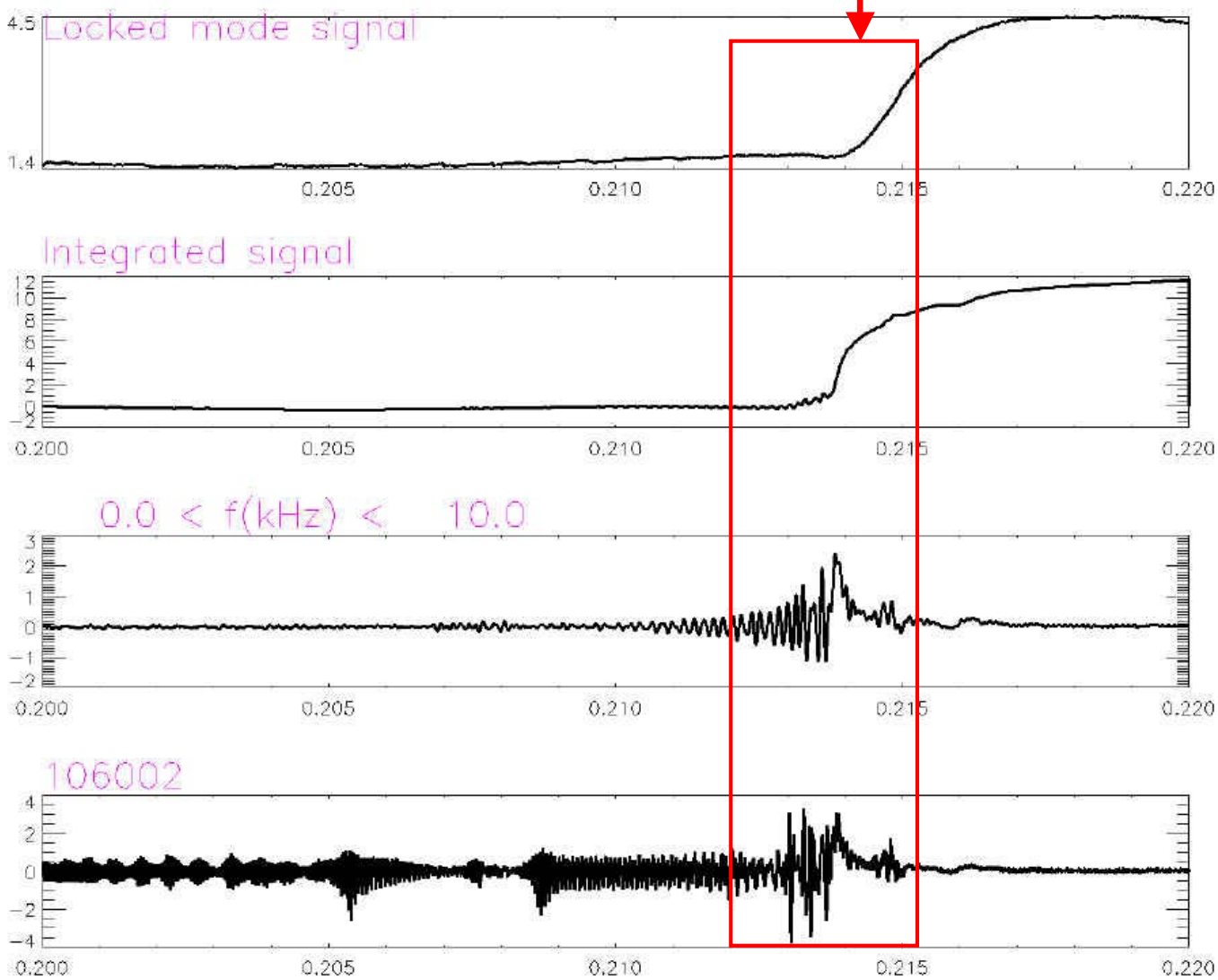
But

There is only a small blip in the locked mode signal at the time of the β collapse



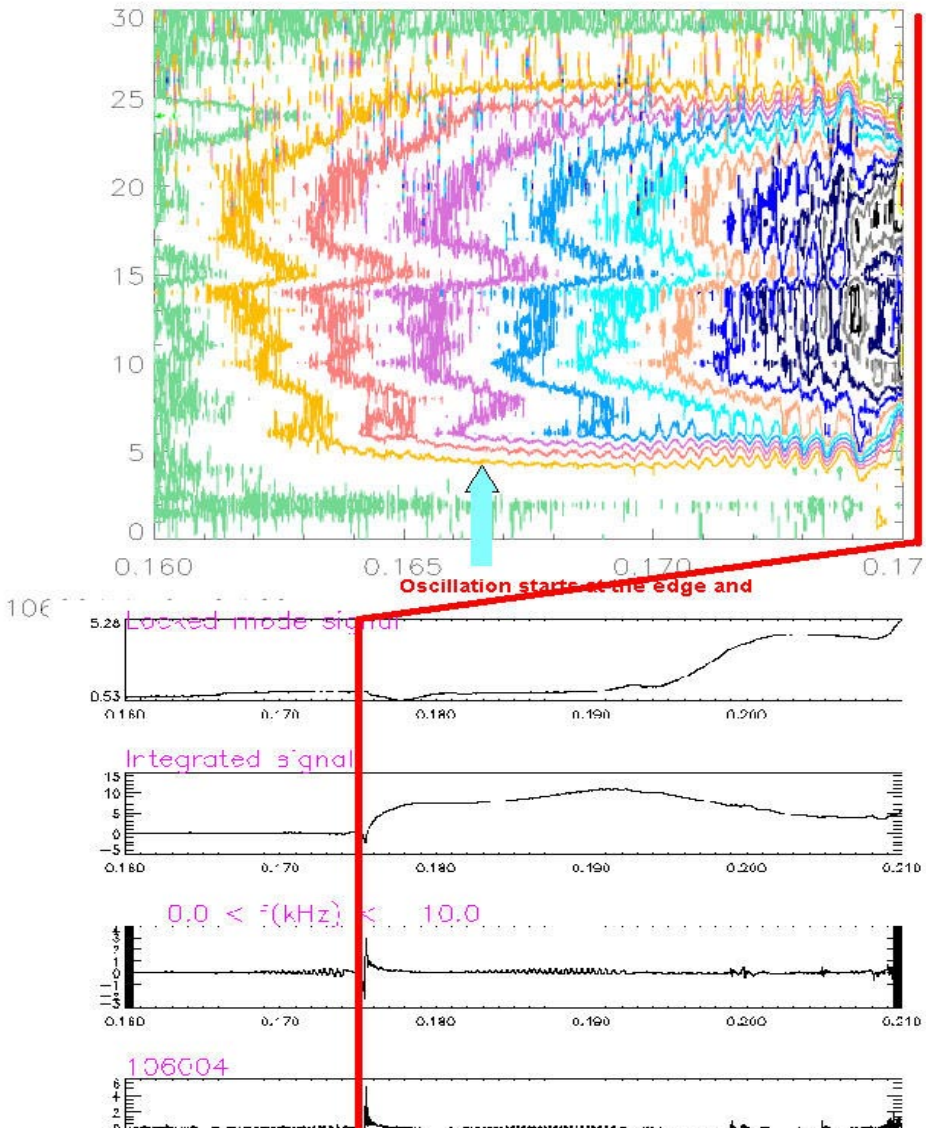
Locked mode Grows at a later time

For some shots there is a large signal on the Mirnov and a large blip in the locked mode signal at the time of the β collapse

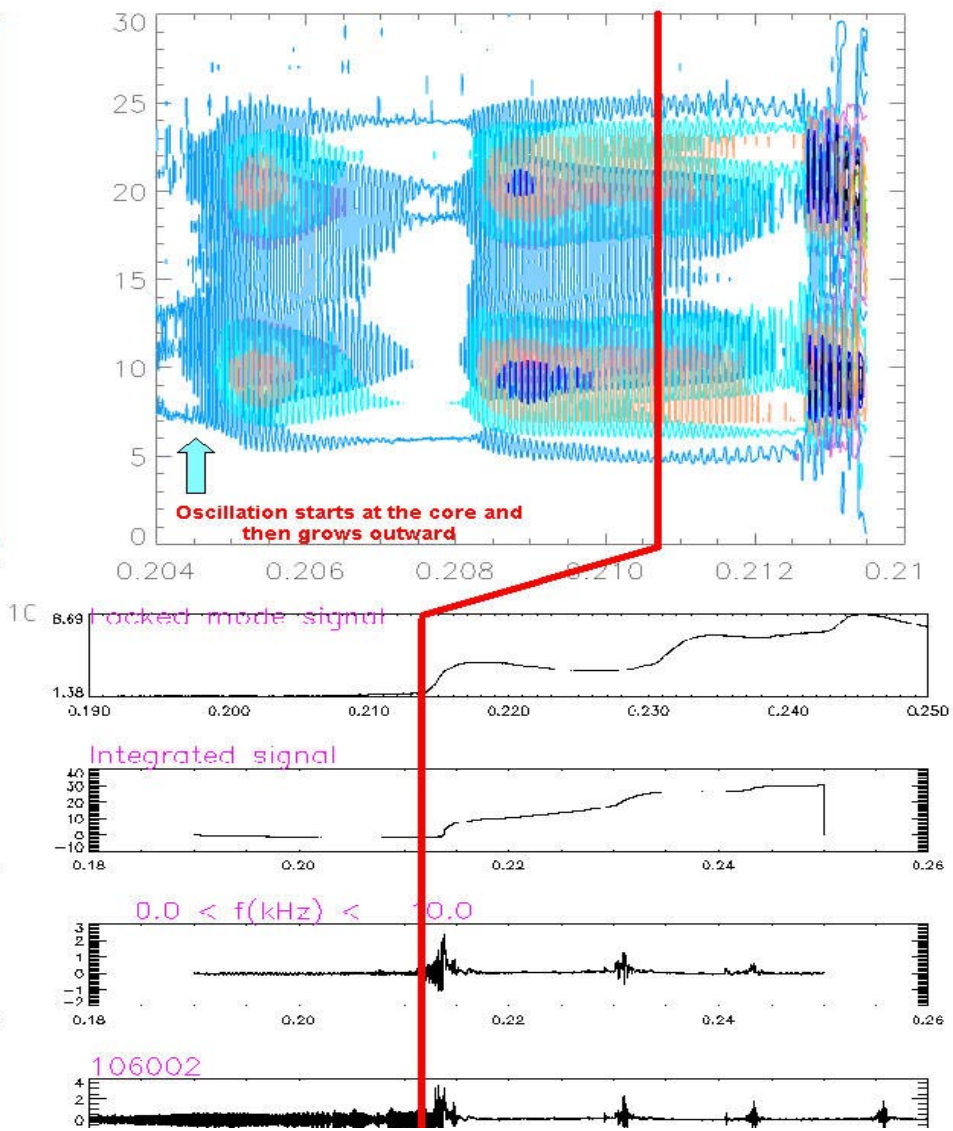


Surprisingly the internal oscillations are larger in the case where there is clear mode-locking

106004

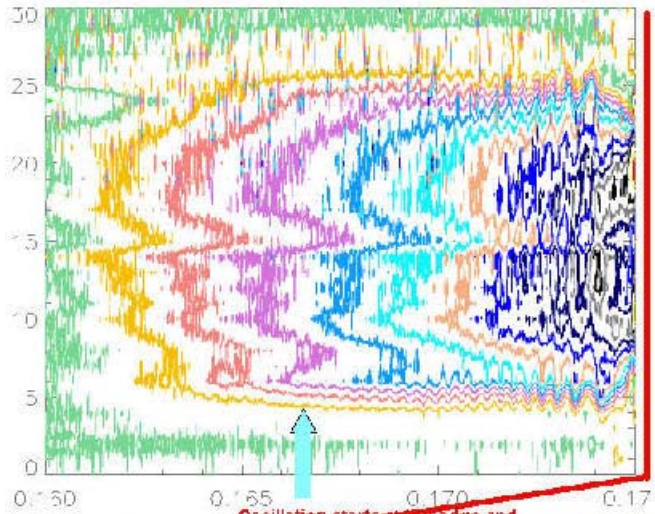


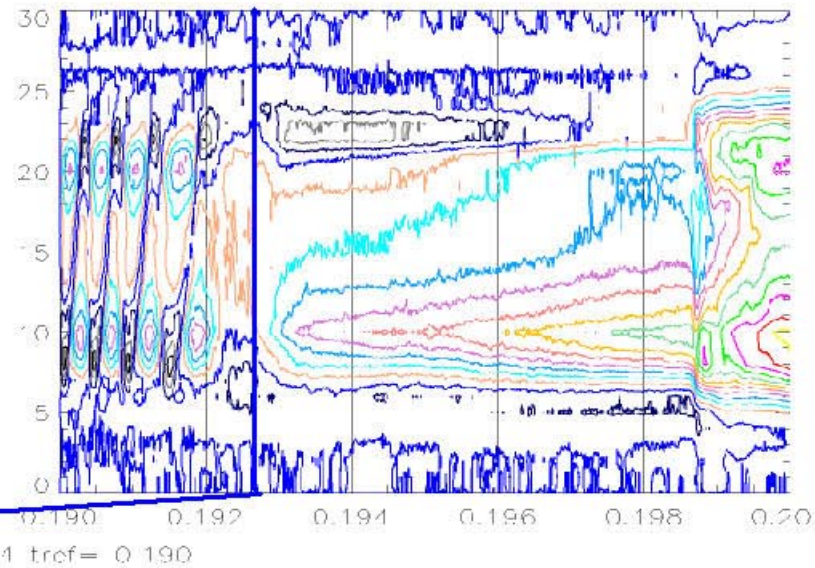
106002

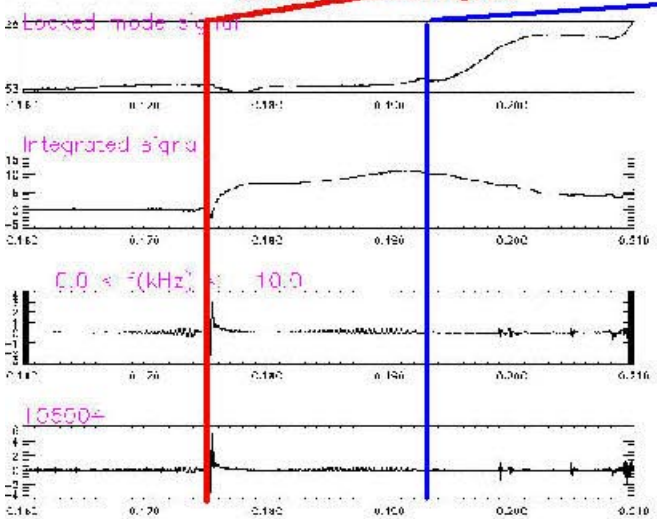


At ~ 0.170 s.
External modes are dominant

At ~ 0.195 s.
Internal modes are dominant



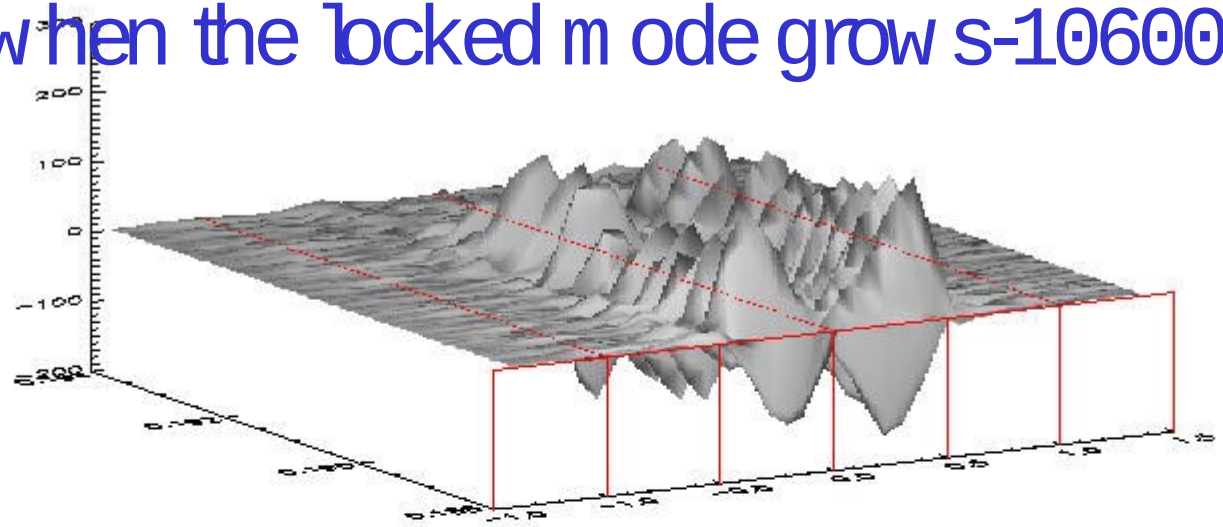


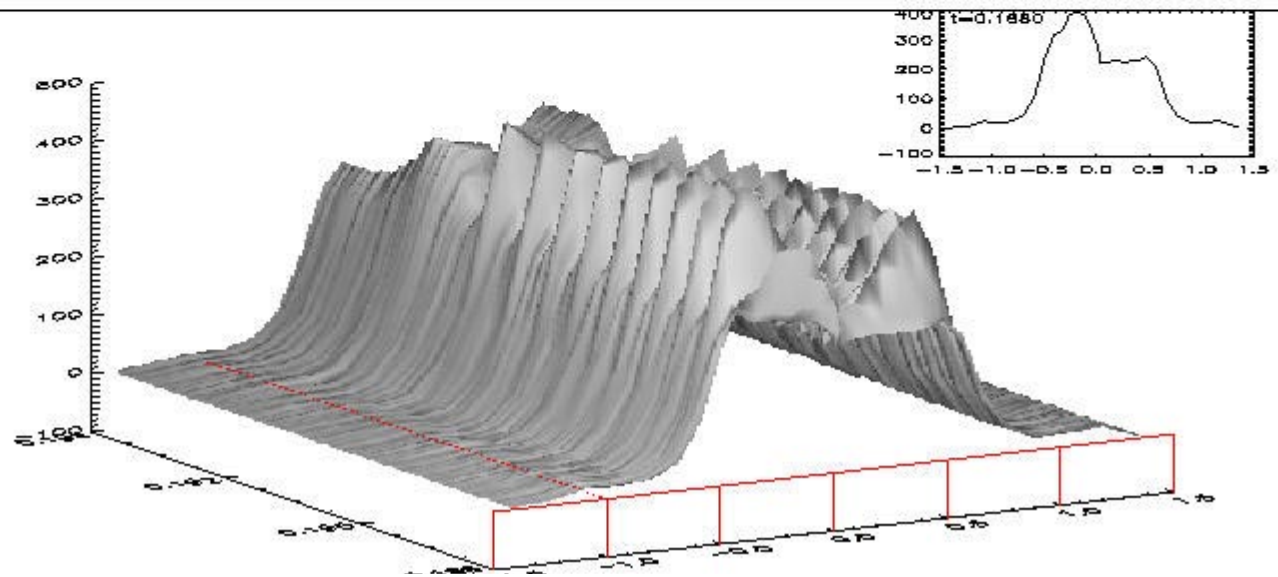


The locked-mode signal grows rapidly at about the same time as a large internal oscillation

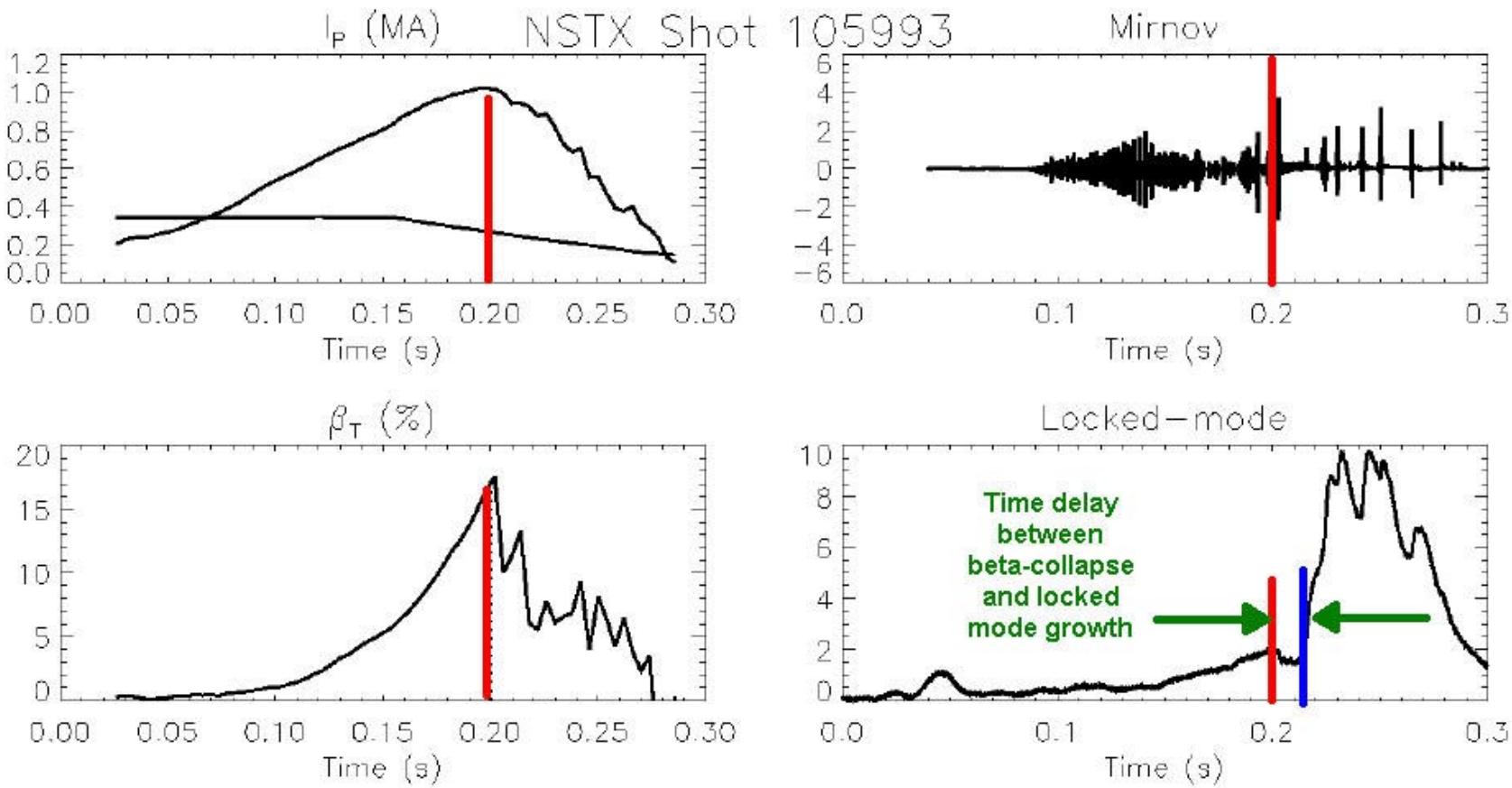
106004

USXR shows internal oscillations at the time when the locked mode grows-106004

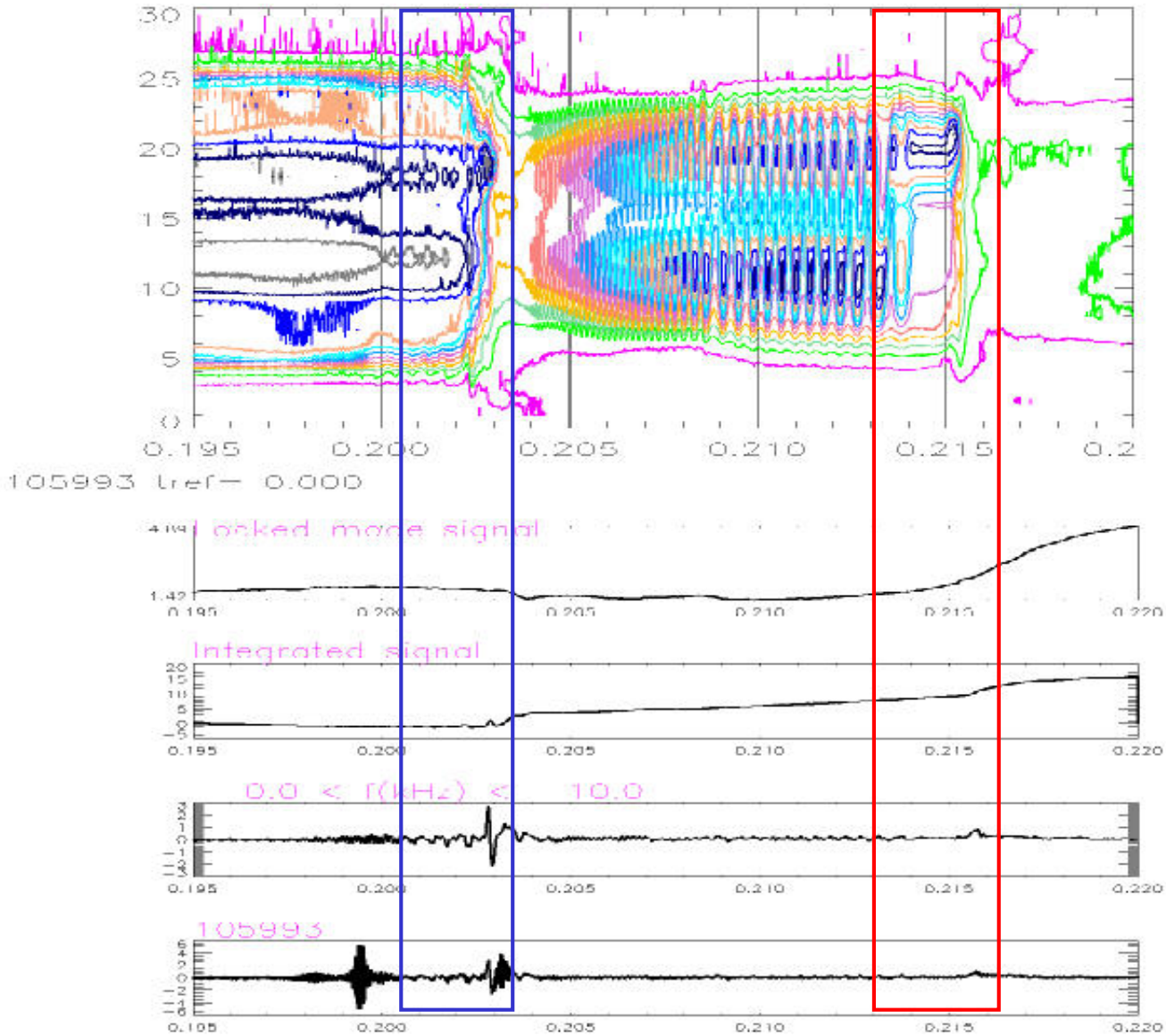




105993 is another shot with an external mode structure and a delayed locked-mode response

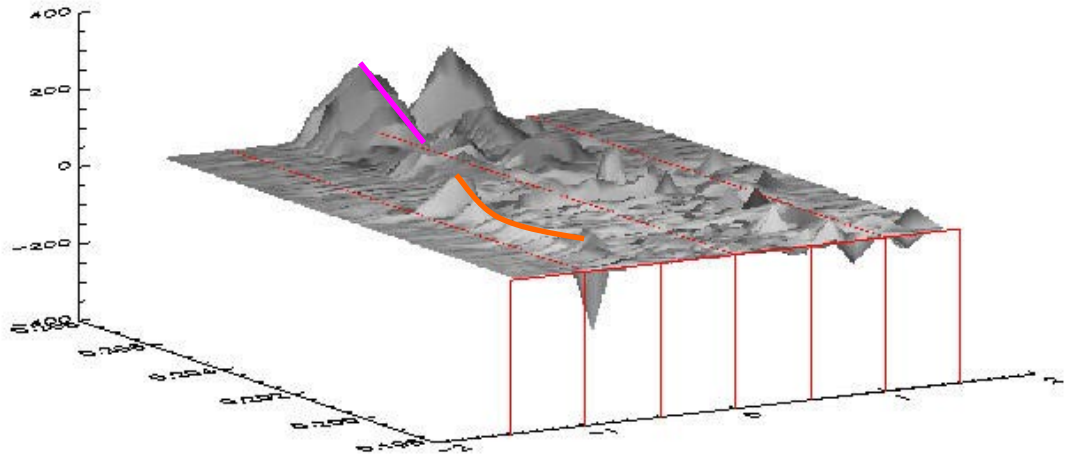


Another example of locked mode growth when a strong internal mode is seen on the SXR

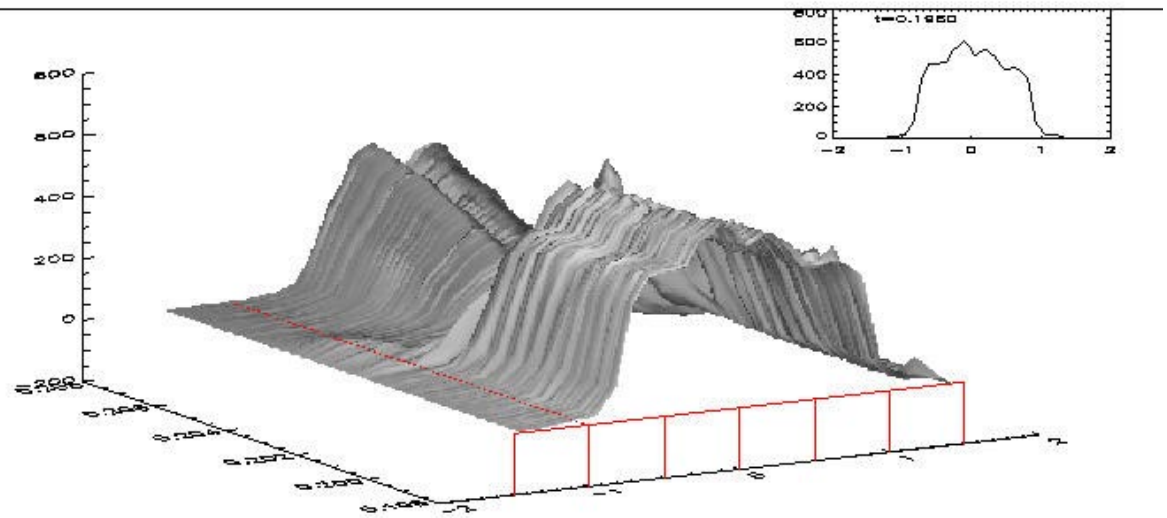


Mode changes from external to internal-105993

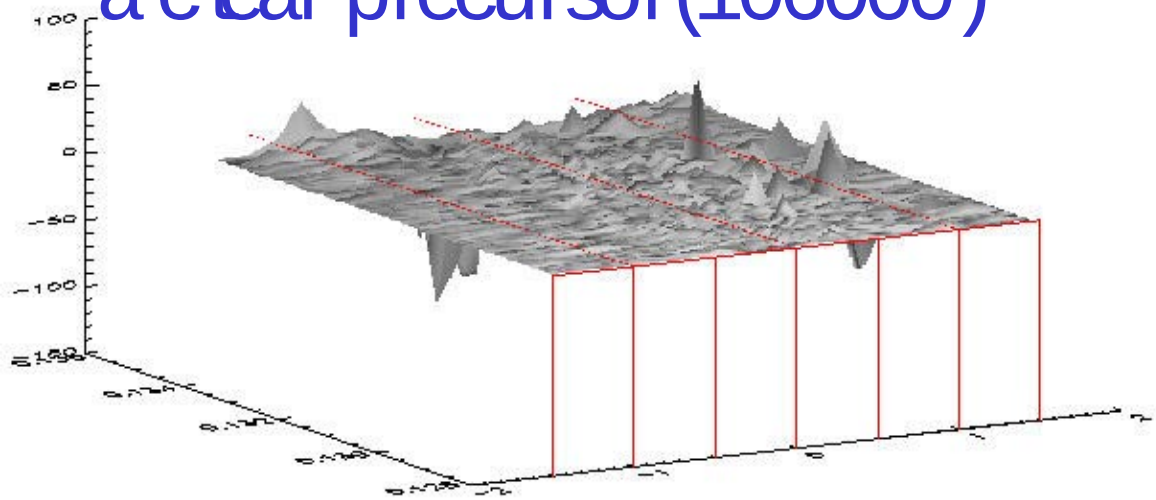
$\delta T = T - \langle T \rangle$

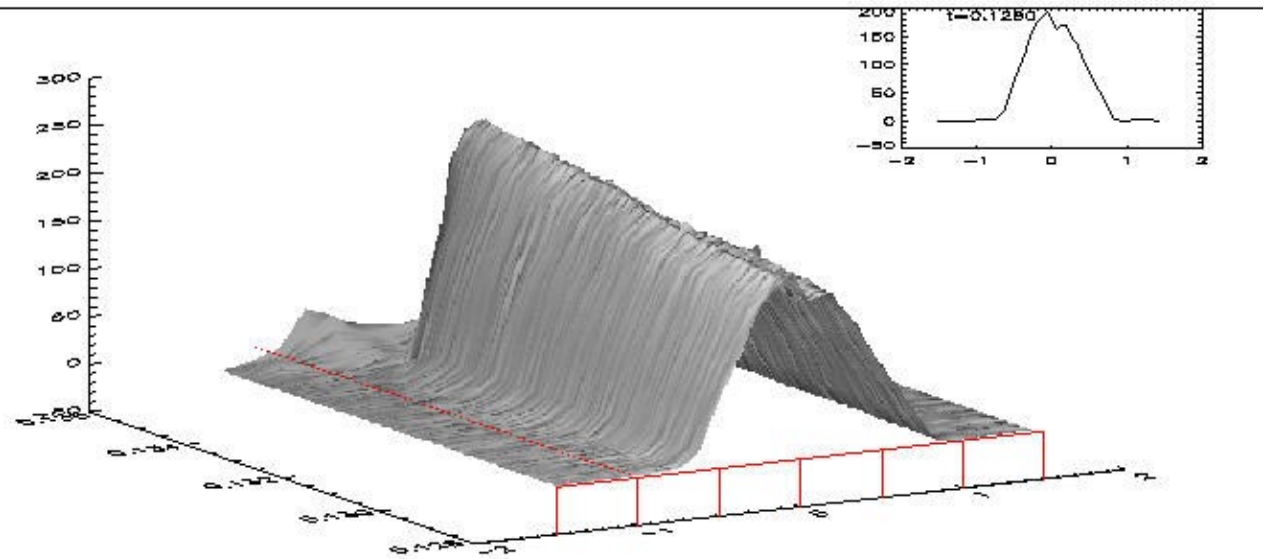


T

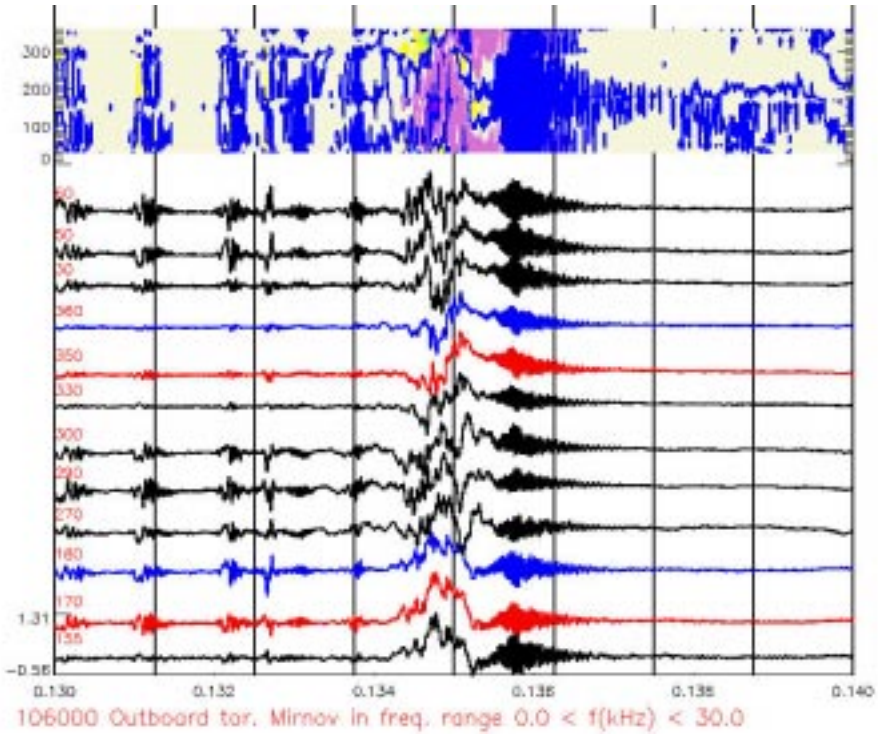


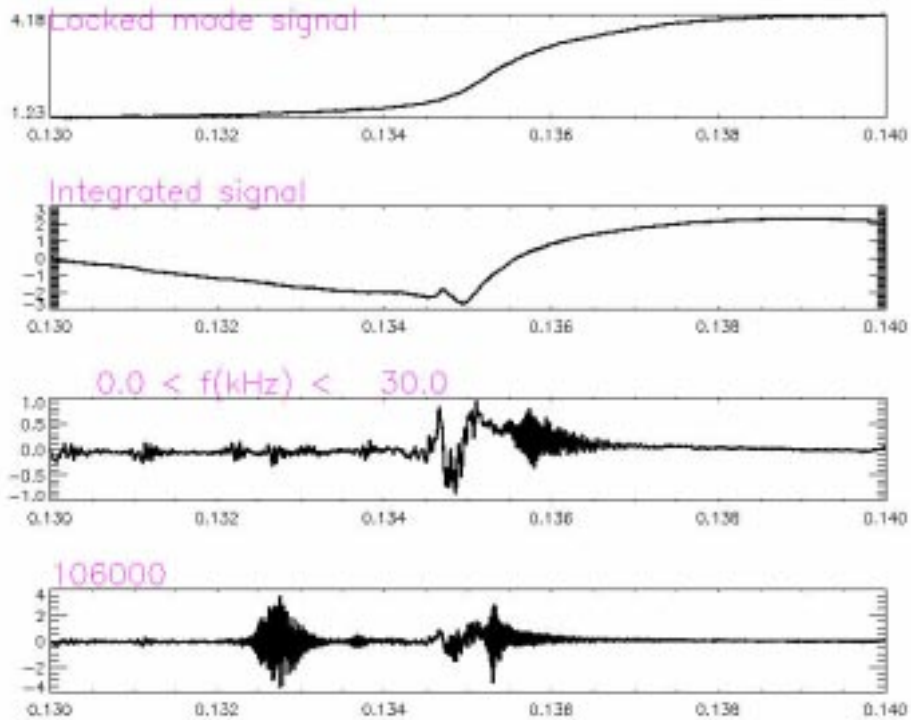
In some cases locked modes are seen without a clear precursor (106000)





Mirnov signals for 106000

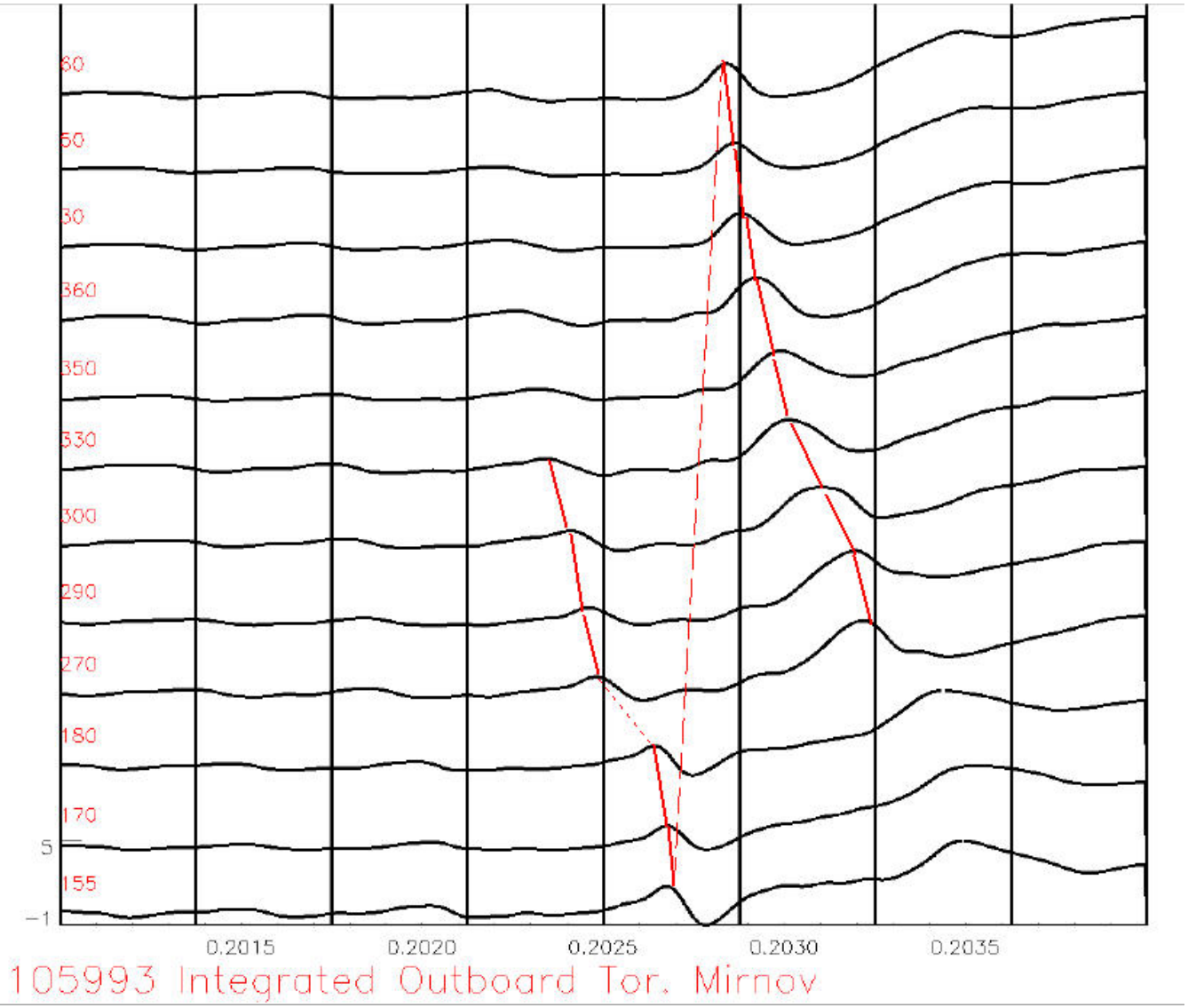




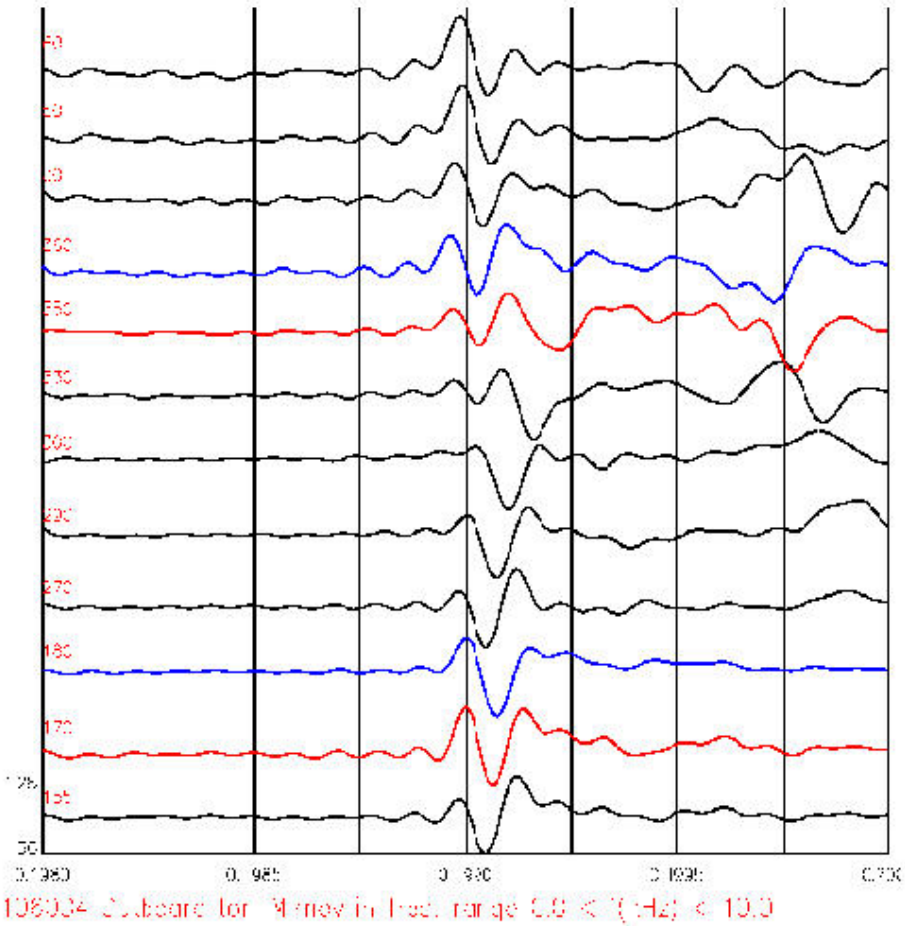
There is a consistent pattern of a smaller rise in the locked mode detector signal when the SXR suggests an external kink!

	Clear external kink		Possible external kink		Internal + external kink		Fast locked mode	
SHOT	106004	106005	105993	105995	106002	106003	105998	106000
B_rad	8	5	5	5	6	8	5	5
B_lock	0.3	0.4	0.5	0.5	3	3	3	3

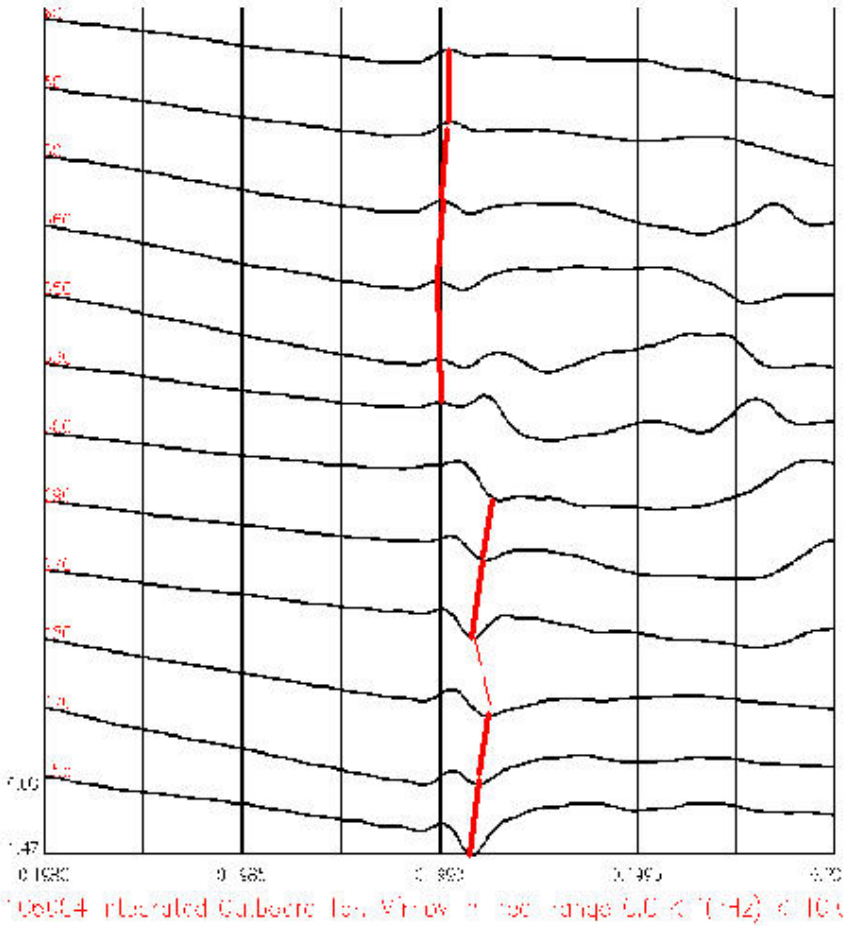
The MHD signals show some unusual structures suggestive of a current filament rotating past the coils-105993



Another example of a CFM -106004



Outboard Mirnov signals (0<f<10 kHz)



Same signals integrated

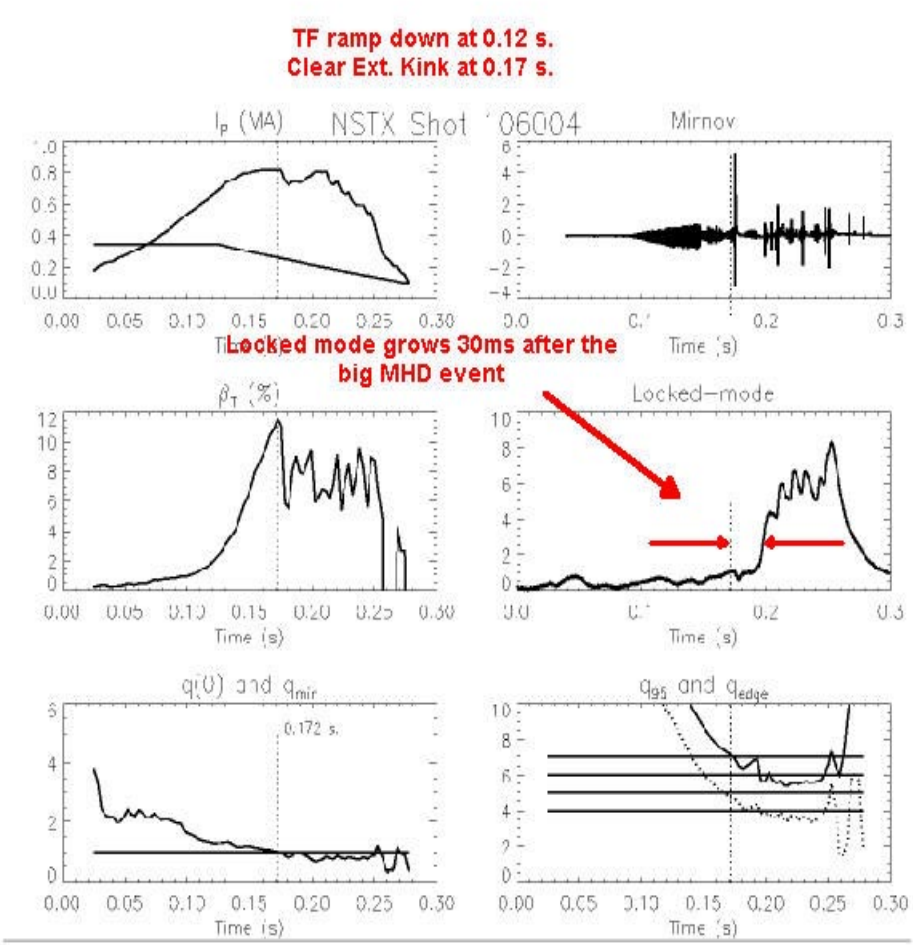
Summary

- An external kink instability was observed under the predicted conditions
- Detailed analysis suggests that mode locking is related to internal modes
- More experimental data needed to unravel some of the new issues raised

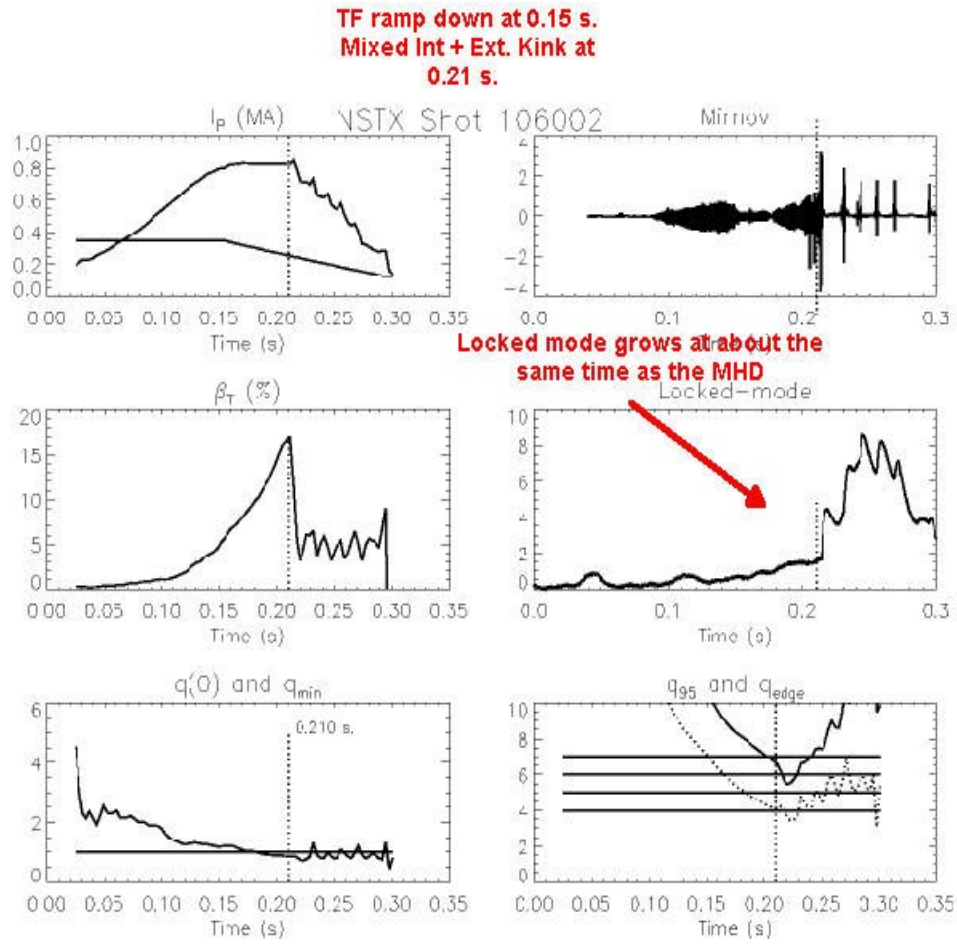
Questions that could be addressed in the next XP

- Can a pure external kink, with no internal component, cause a disruption?
- Does the external error field couple to the edge or the core?
- What is the role of rotation on mode stability?
- Is there an influence of the wall, i.e. is the mode a kink or a RWM ?
- Does the mode have a real frequency in the plasma frame?
- What is the non-linear behavior of the kink, does it relate to production of a current filament?
- Can we characterize the CFM, current filament mode, and does it play a role in mode-locking?

Comparison of clear ext. kink and mixed int.+ext. kink



q-axis ~ 1 at T-MHD



q-axis < 1 at T-MHD

NSTX

There is a consistent pattern of a smaller jump in the locked mode detector signal when the SXR suggests an external kink!

SHOT		Time	Efit-beta	E-qmin	E-q95	E-li	E-Ip	J90%	γ (msecs)	γ-H (msecs)	Walltime	B_locked	Tor.Angle	T_lock	T_lock	T_lock
106004		0.17	11	0.998	4.66	0.7	648	10.6	2.5	27.7	3.4	1.1	150	0.196	8	0.3
106005		0.17	11.2	1	4.75	0.7	651	10.1	2.6	30	3.5	1.2	150	0.189	5	0.4
106009		0.17	13.9	1.05	4.94	0.6	760	13.1	2.8	20	3.9	2	180	0.206	4	0.6
106002		0.21	16.5	0.88	4.4	0.8	658	8	0.6	22.5	1.6	2	150	0.214	6	3
106003		0.21	16.5	0.87	4.3	0.8	658	8	0.4	28	1.7	2	150	0.217	8	3
106006		0.2	15.8	0.83	4	0.8	568	8.8	2.3	38	3.6	1.8	150	0.204	8	2
106007		0.2	14.6	0.82	4	0.8	570	9.1	0.9	36	1.1	2	150	0.204	7	2
105993		0.2	17.6	0.93	4.1	0.6	810	11.8	1.3	28.6	3.8	2	150	0.198	5	0.5
105994		0.17	12.1	1.04	4.8	0.6	727	13	3.5	36	3.3	1	150	0.213	5	0.5
105995		0.17	12.5	1.03	4.74	0.6	724	12.7	3	27.6	1.6	1.5	150	0.207	5	0.5
106008		0.17	11.6	1.06	5.3	0.7	572	9	2.1	22	2.5	1.8	150	0.192	6	0.6
105998		0.14	6.5	1	5.7	0.6	590	14.1	0.4	36	1.5	2	330	0.14	5	3
106000		0.13	5	1.1	6.5	0.6	540	14.7	0.4	18	1.4	2	330	0.135	5	3
106001		0.14	3.4	1.04	5.9	0.6	574	14	0.4	56	1.5	1.5	15	0.143	3	2
106010		0.15	8.5	1.11	5.8	0.6	668	12.7	0.8	36	3.4	2	300	0.156	0.156	0.156

Signature of ideal kink

- Large perturbation at plasma edge ✓ ✓
  - Small or no perturbation in core ✓
  - Low frequency non-axisymmetric mode ✓
- Correlation with q_95 ✓
- No island structure on SXR contours ✓ ✓
- Mode frequency not locked to plasma ✓
- Parametric dependence ✓

So what's the problem?

- Uncertainty in profile
- Mode frequency in plasma frame, requires rotation data
- Coupling to internal modes
- Role of error fields
- Mode locking