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NSTX-U

Some L-mode observations

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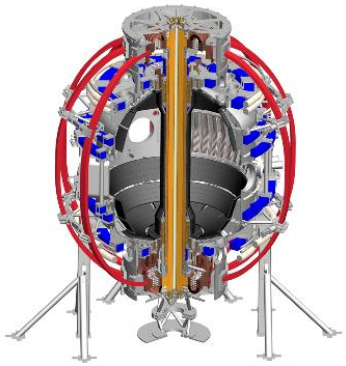
MHD TSG Meeting
6/14/2016

PPPL

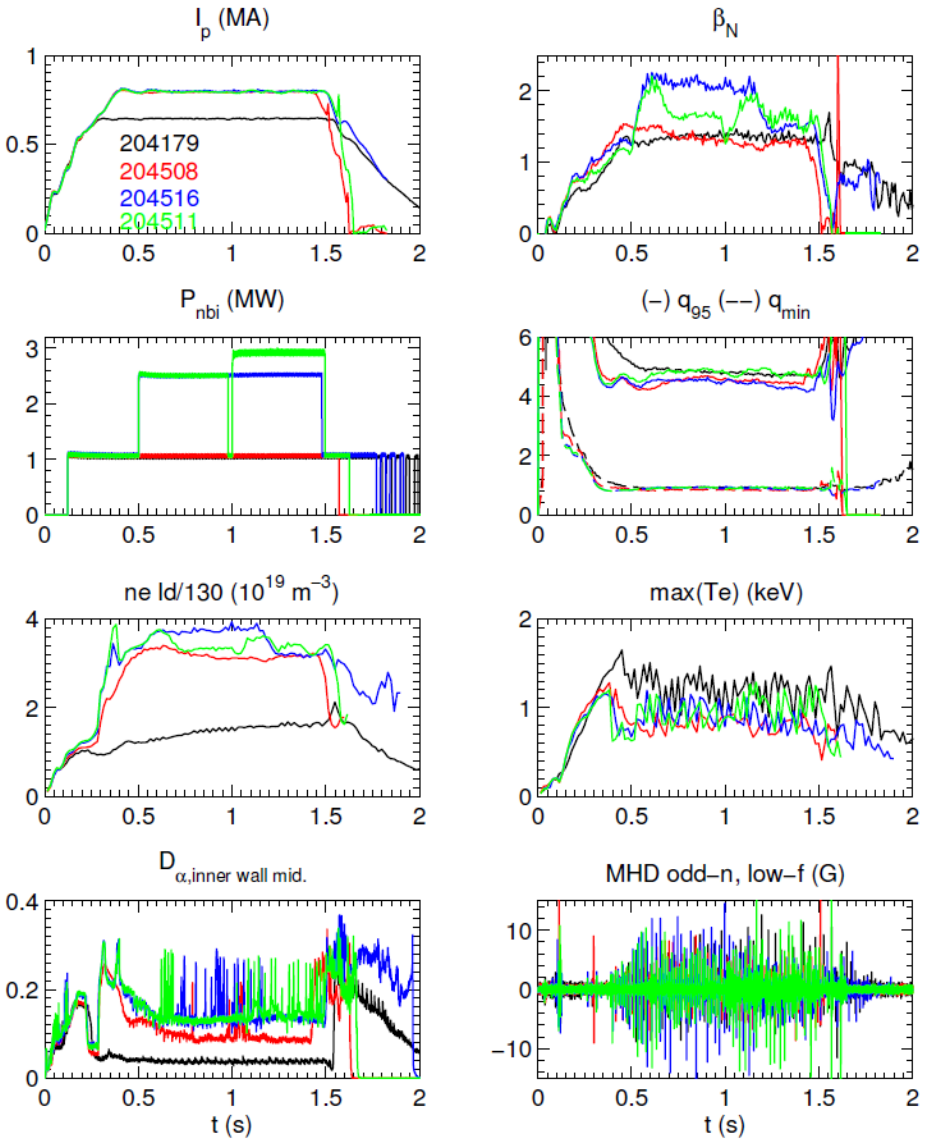


Overview: Some L-mode observations

- Sawteeth present (inversion radius ~ 125 cm)
- Strong n=2 mode often develops (~135 cm), typically after L-H-L, pulls down core rotation and density
- Edge rotation (R>140 cm) in L-modes always(?) locked
- Examples of unlocked edge rotation in H-mode

800 kA L-modes achieved w/ increased HFS fueling & NBI 1 power

- Increased I_p from 650 to 800 kA
- Increased HFS fueling to eliminate L-H
  - Initial increases in LFS had little effect – **would like to revisit this**
- Sustained shots with up to 2.5 MW (1B+1A) and 2.9 MW (1B+1C), β_N>2
  - Tried up to 3.5-4.3 MW but shots die from MHD (often associated with L-H/H-L)
- Crazy MARFE-like "dancing rings" observed in inner wall midplane spectroscopy (D_α, O II, C II)
- All shots sawtoothing (Δt~35 ms, R_{inv}~125 cm)
  - Faster, weaker sawteeth (Δt~20 ms) with higher density and/or NBI 1C?
- Drop in n_e, β_N often seen due to strong n=2 MHD (e.g ~1.2 s in 204516)



EFIT q=1 surface very close to sawtooth inversion radius (~125 cm)

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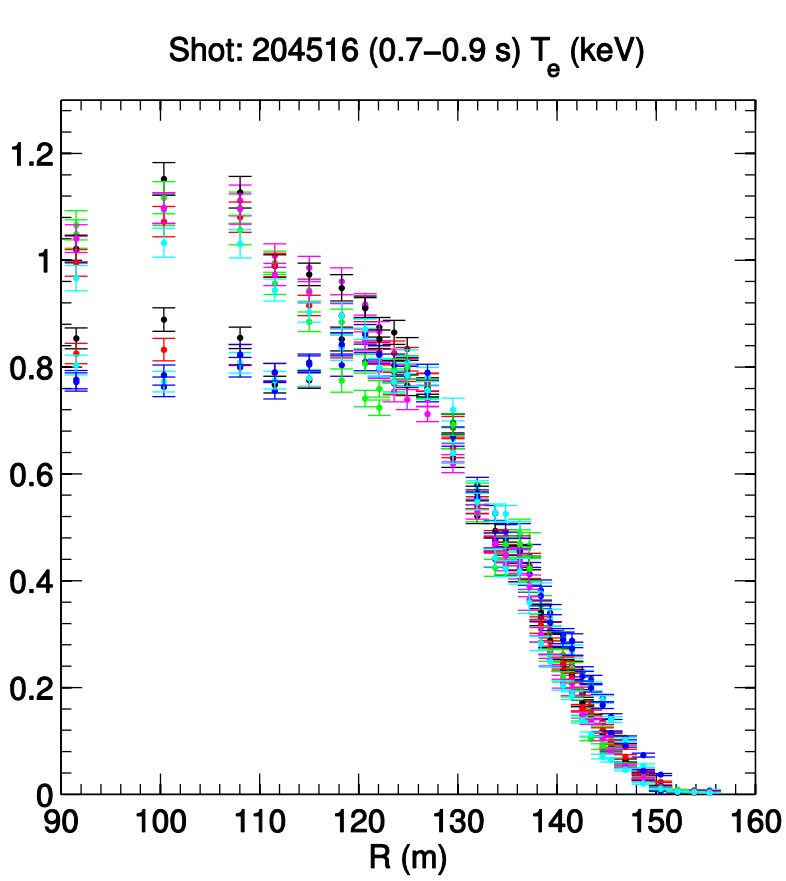
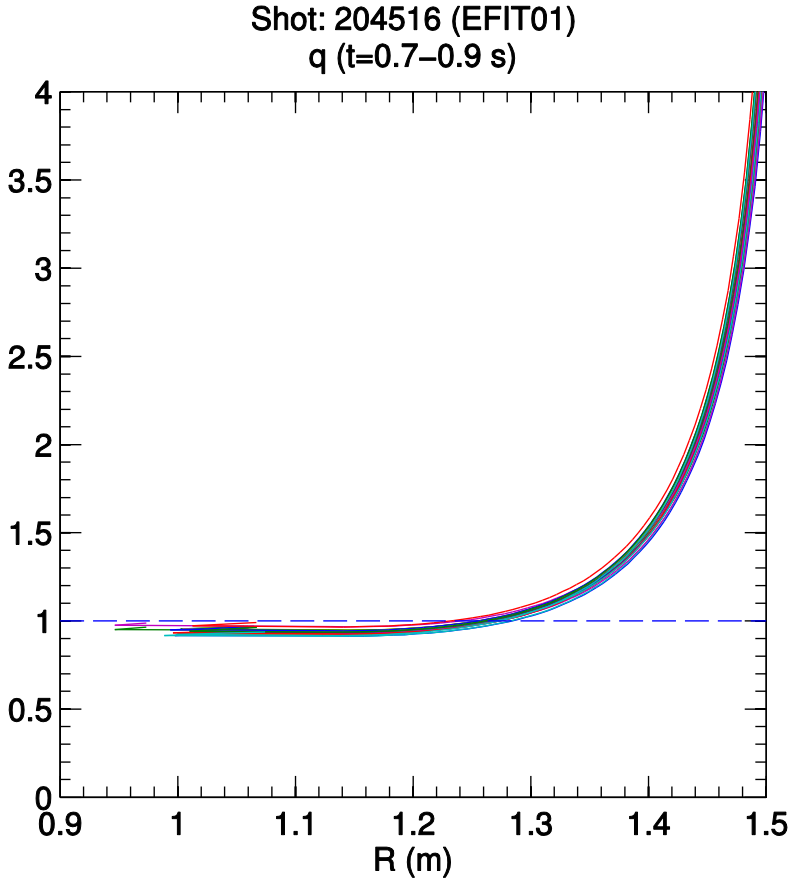
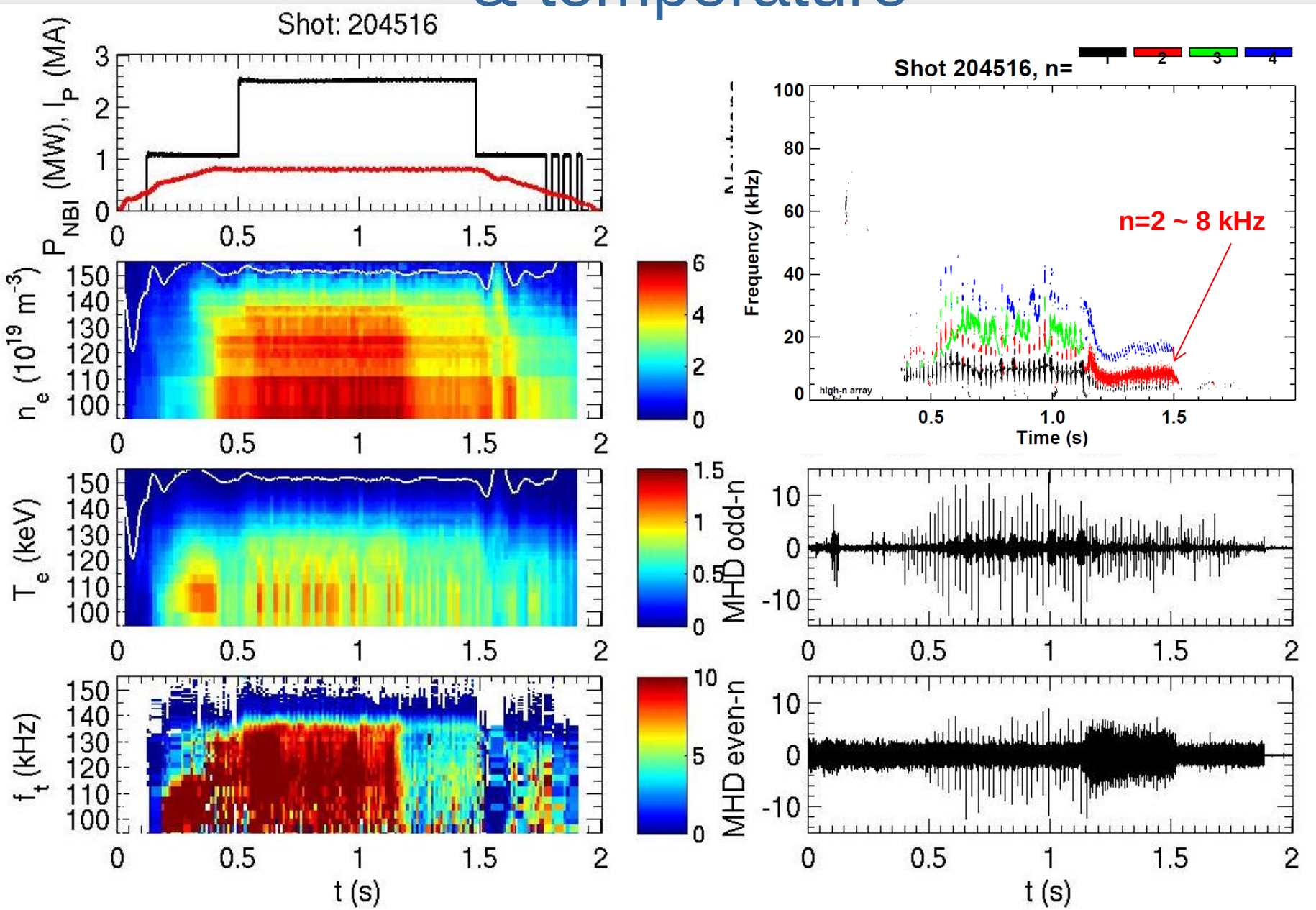
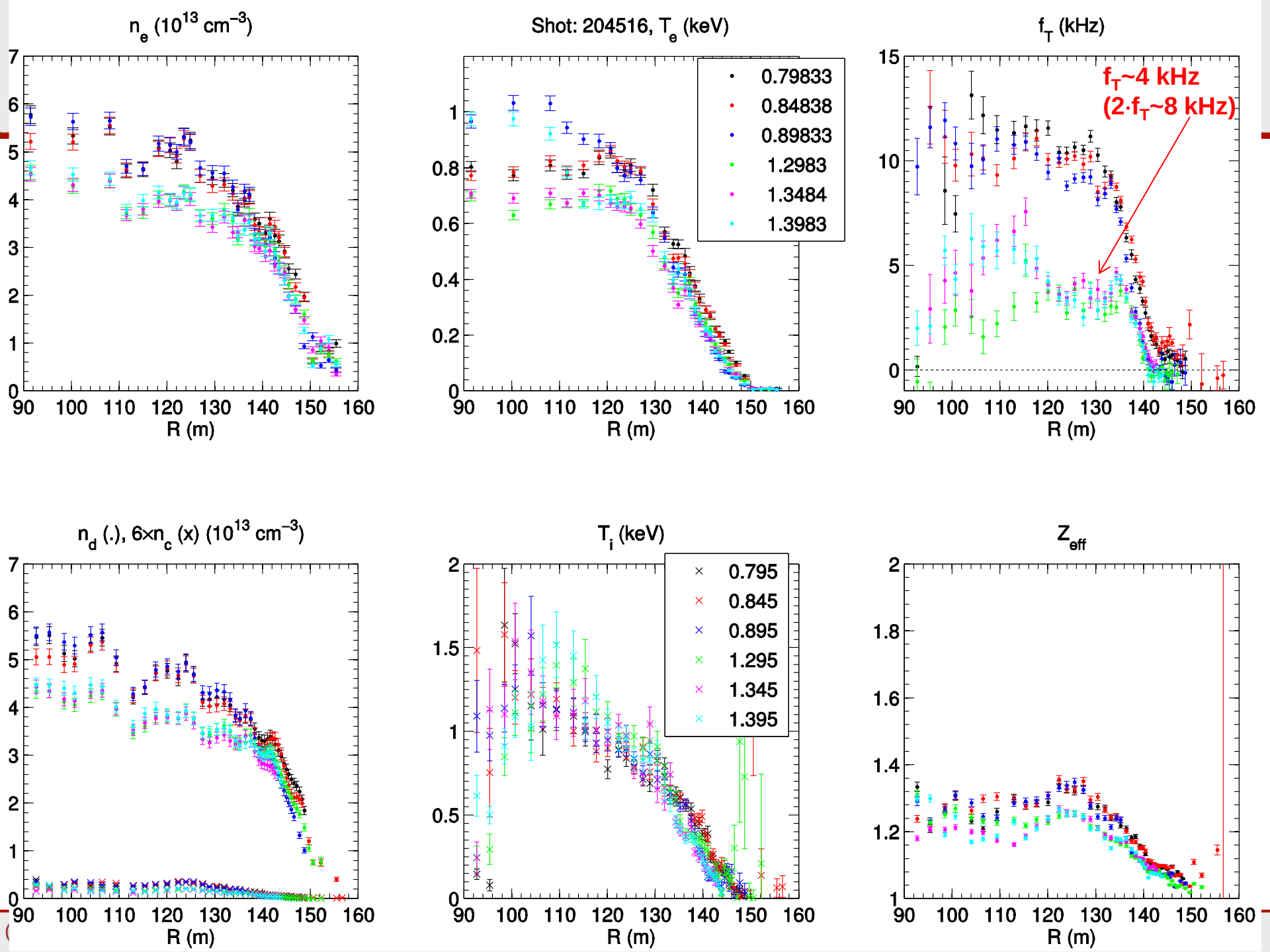




Strong n=2 pulls down core rotation, density & temperature

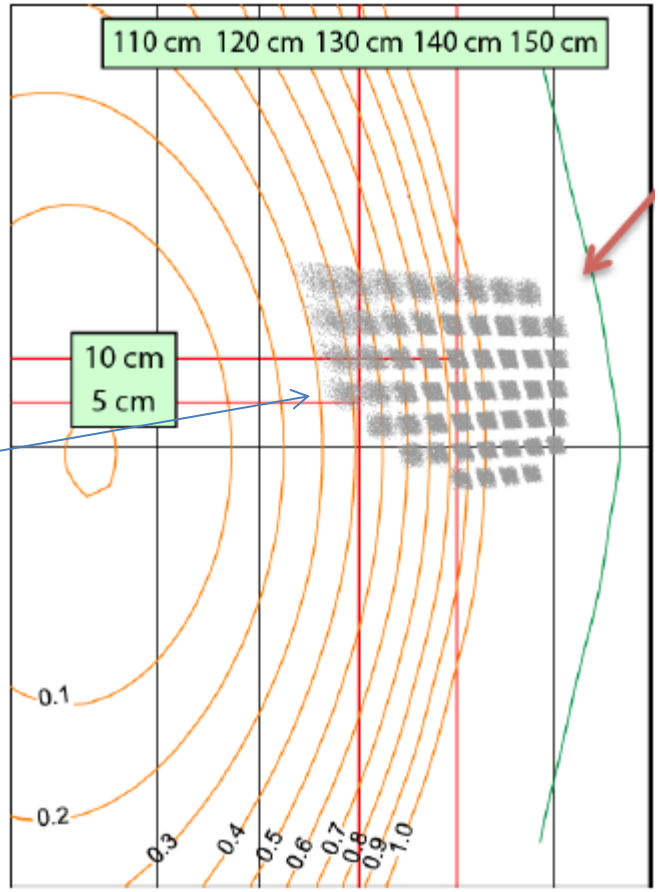



n_e (10^{13} cm^{-3})
R (m)
Shot: 204516, T_e (keV)
0.79833
0.84838
0.89833
1.2983
1.3484
1.3983
R (m)
f_T (kHz)
f_T~4 kHz
(2·f_T~8 kHz)
R (m)
n_d (.), 6×n_c (x) (10^{13} cm^{-3})
R (m)
T_i (keV)
0.795
0.845
0.895
1.295
1.345
1.395
R (m)
Z_{eff}
R (m)

BES acquiring data for most of these shots

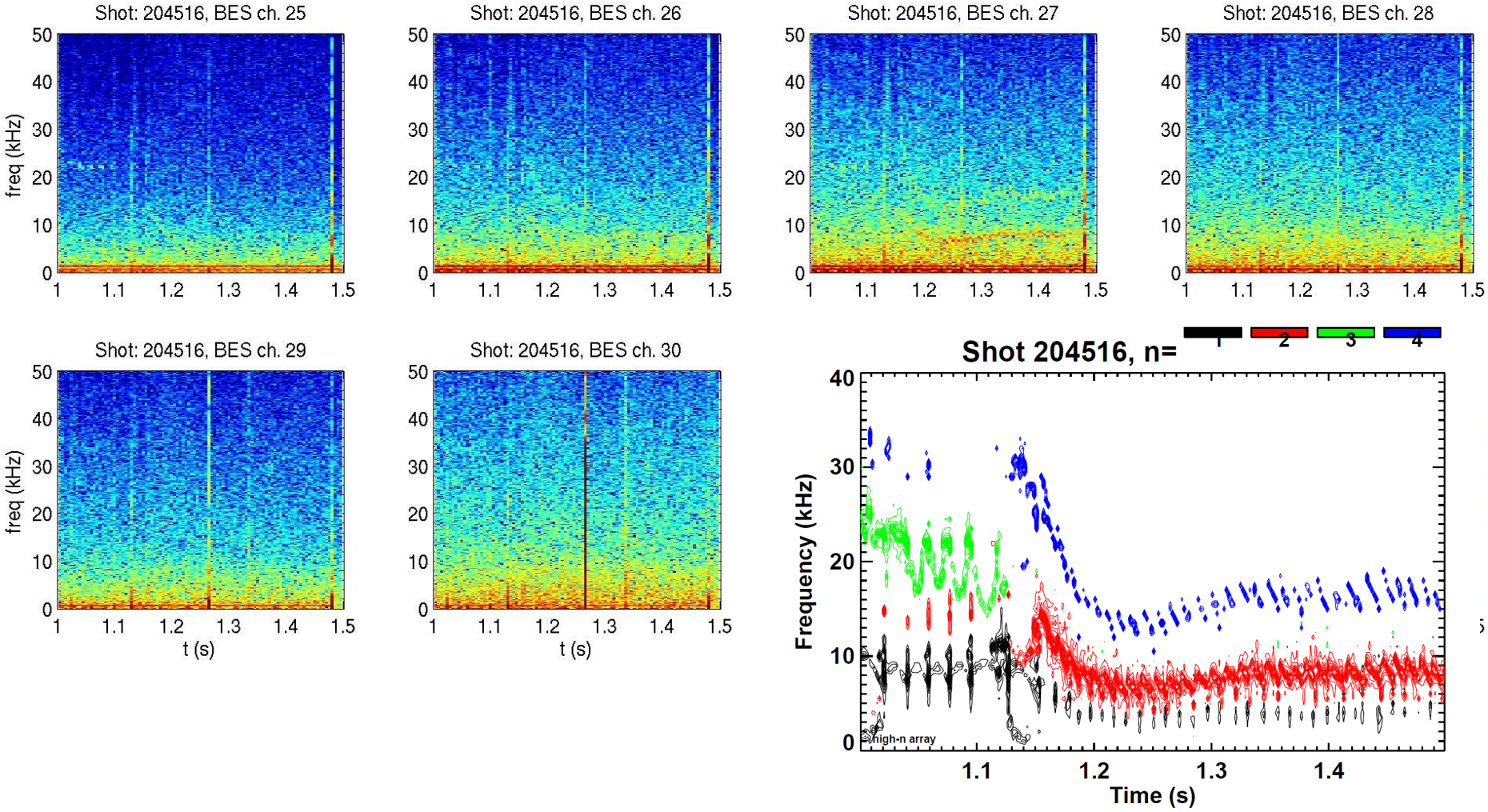
- 2D array of channels

- Row 1: ch 1-8
- Row 2: ch. 9-16
- Row 3: ch. 17-24
- **Row 4: ch. 25-32**

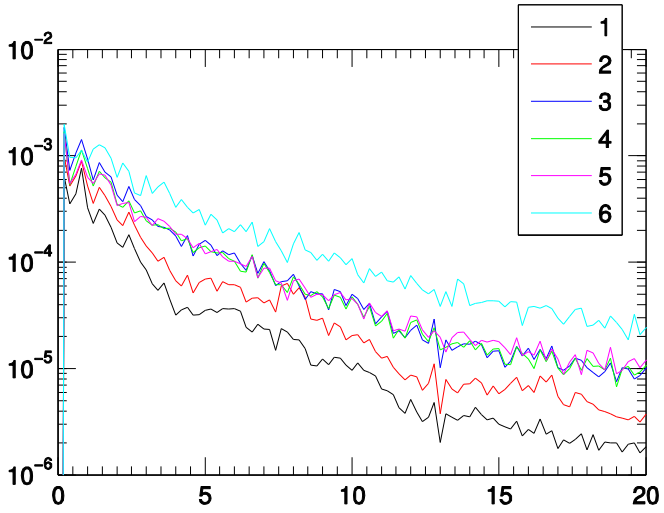


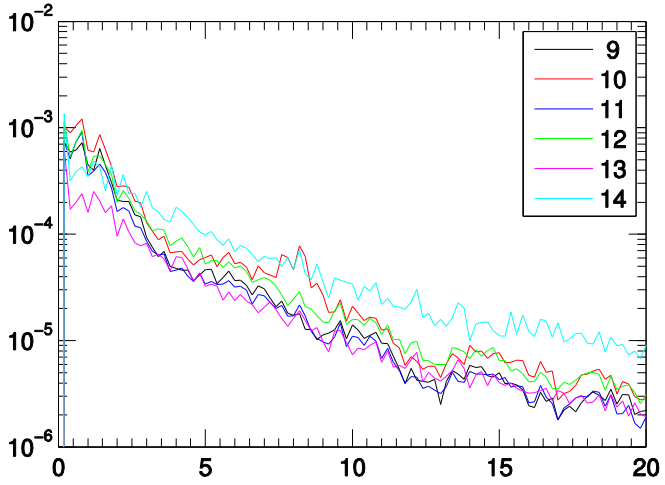
Small density perturbation associated with n=2 observed around R=134 cm channel

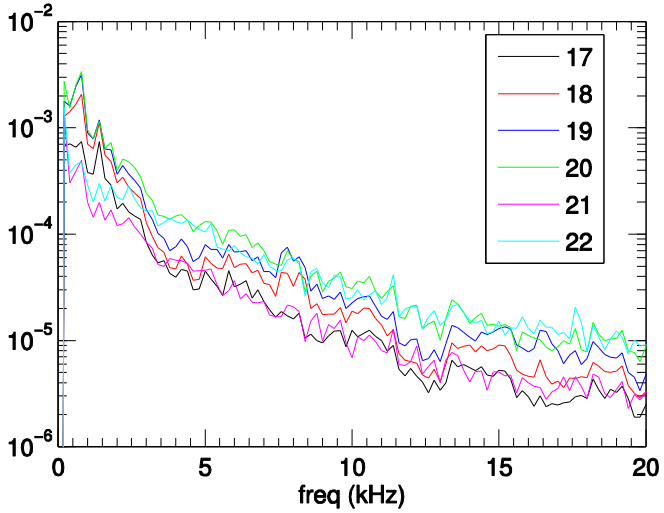
- $R_{BES,27}$~134 cm

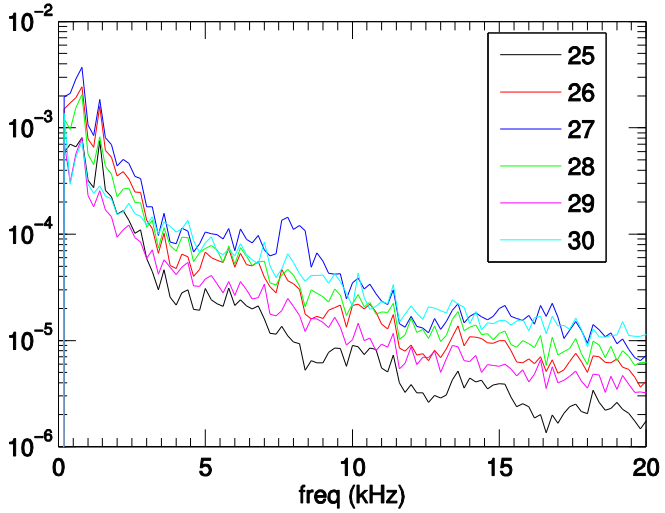


Observed in 1-2 channels in each row of BES data









q profile from EFIT01
Edge rotation (R>140 cm) also locked

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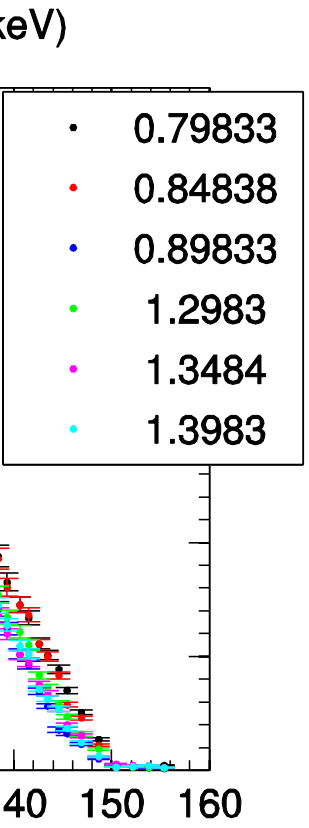
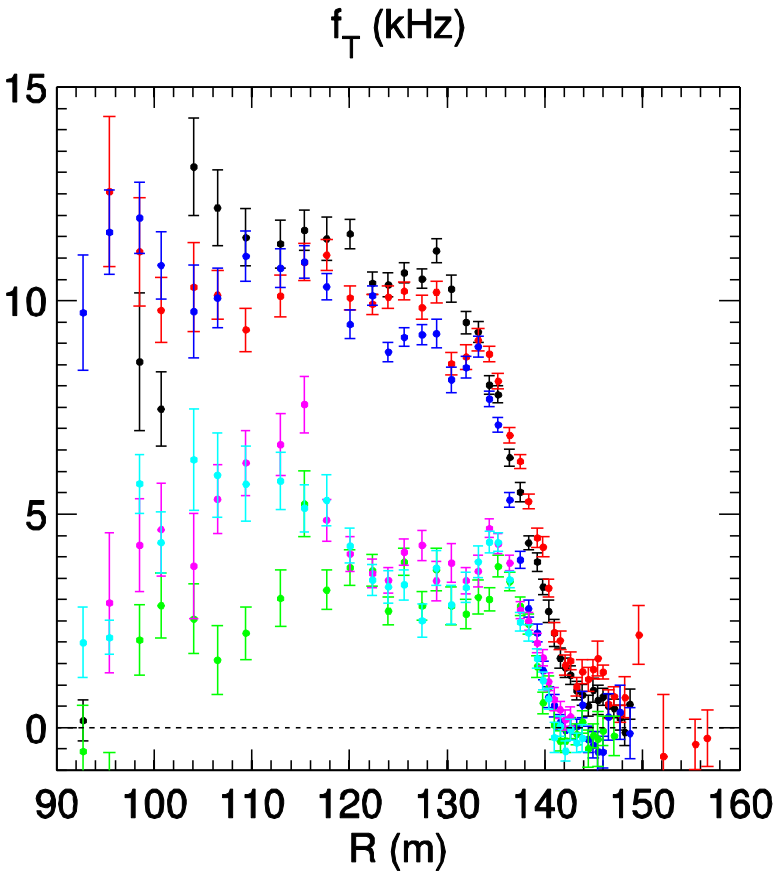
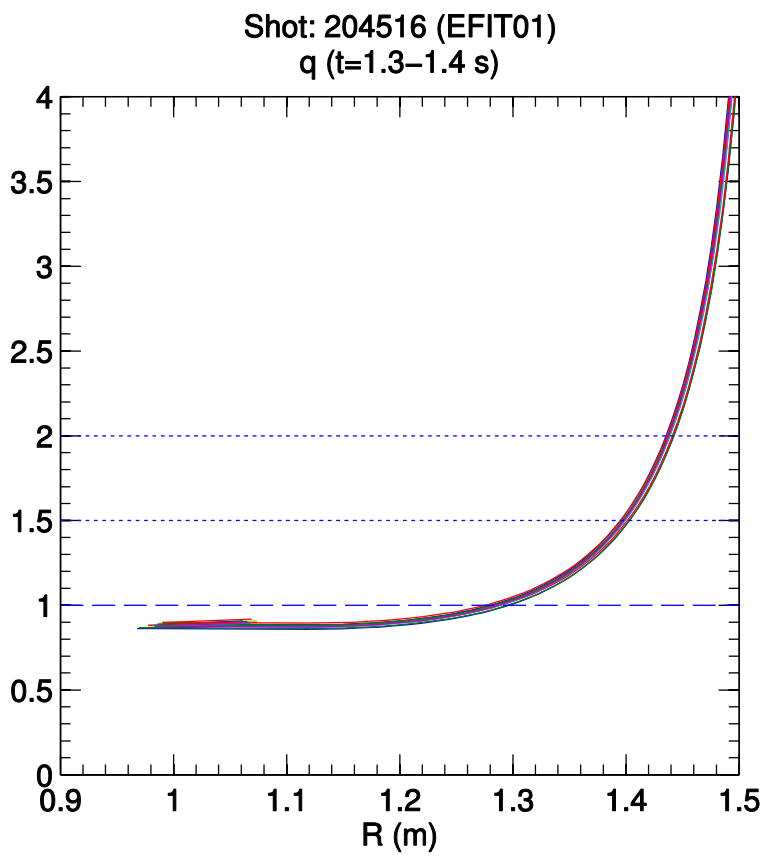
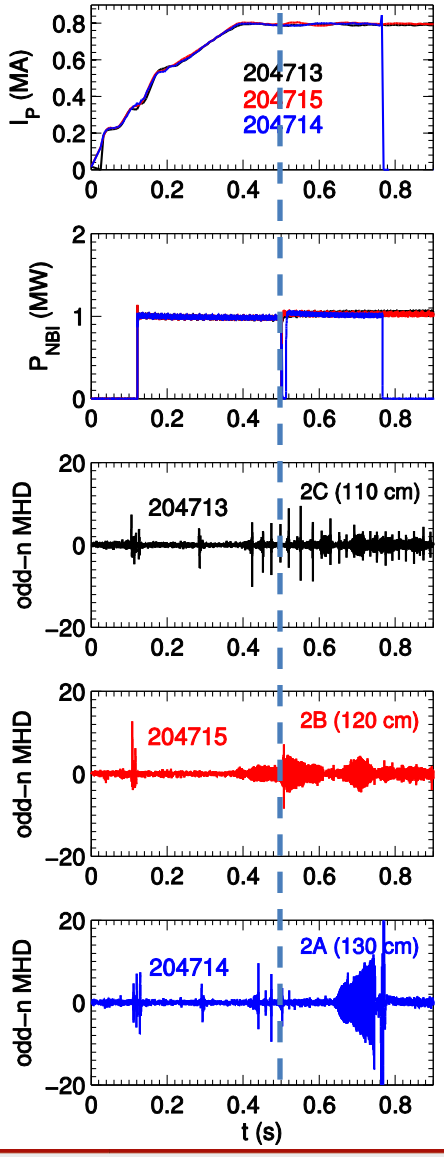


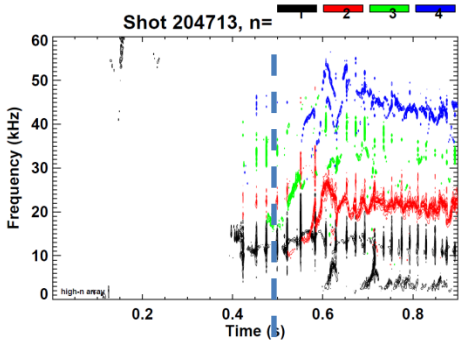


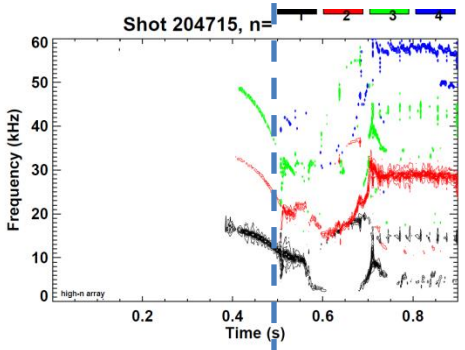


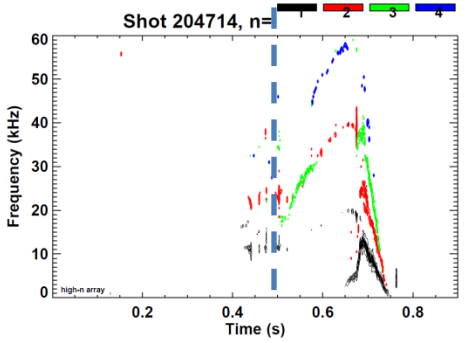
Part 2A (5/13/2016) – First attempt trying all 6 NBI sources individually (1 MW)



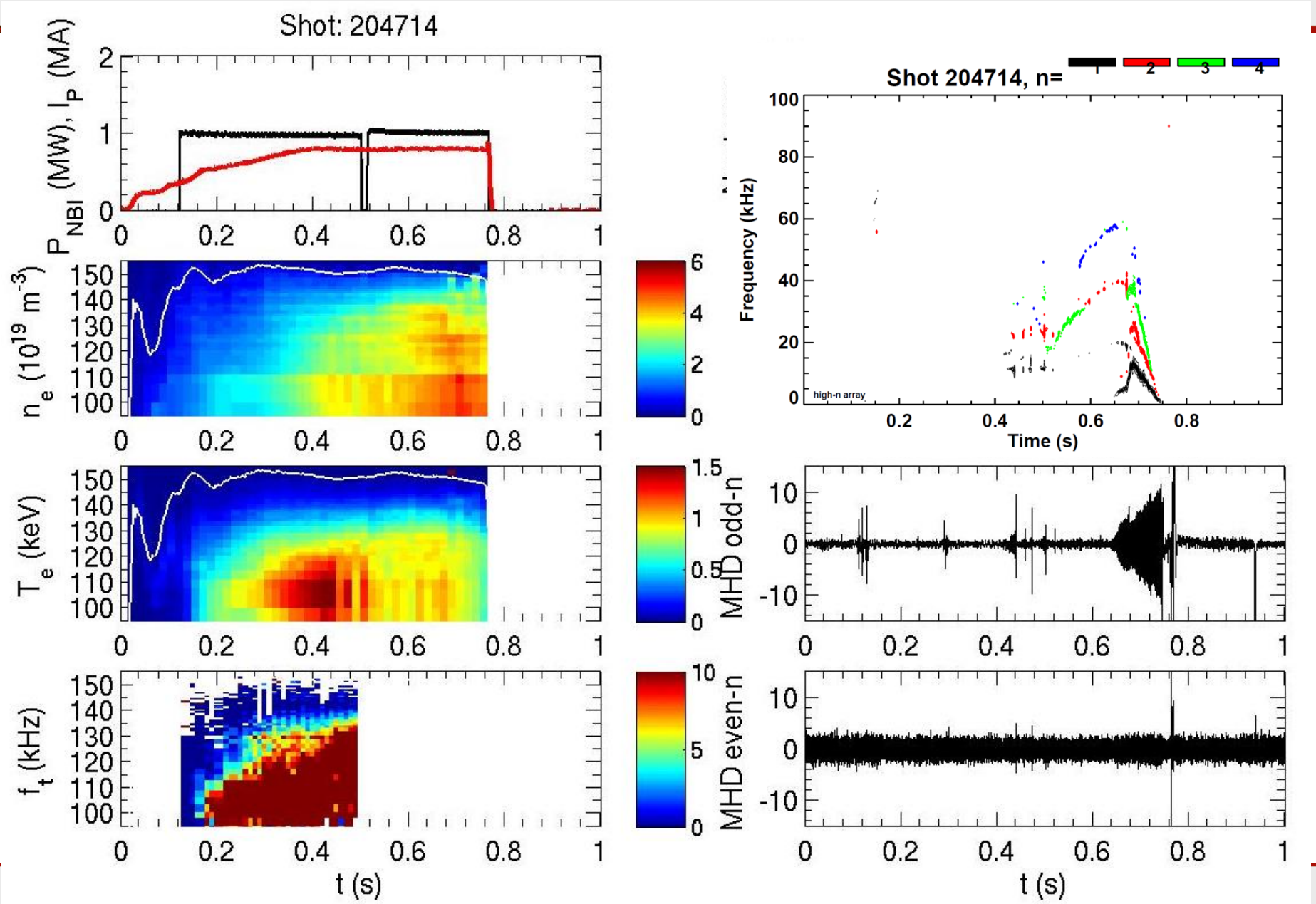
- Incorrect fueling (lots of L-H-L) and an unrealible beam – **would like to repeat with reliable fueling & heating**



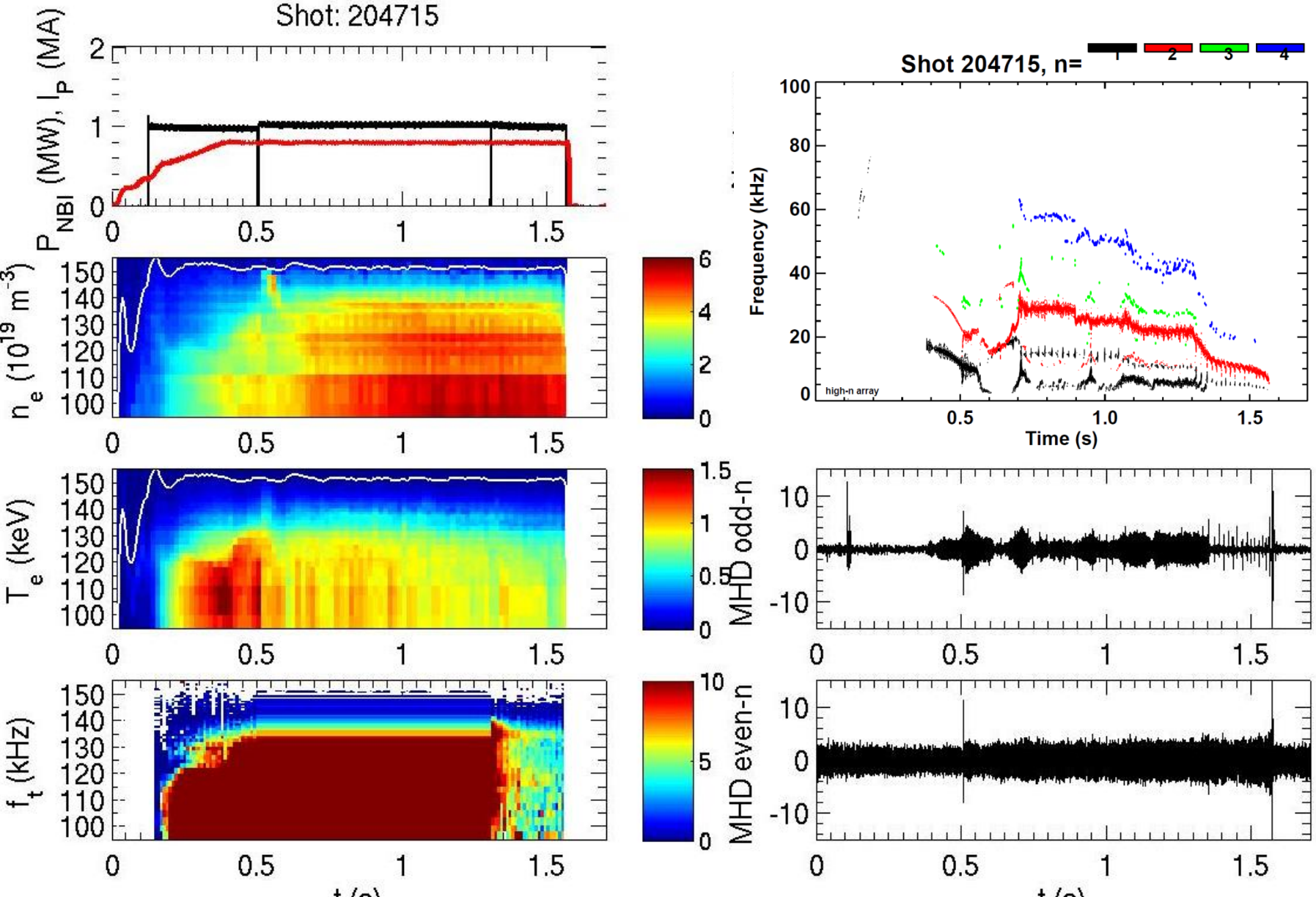




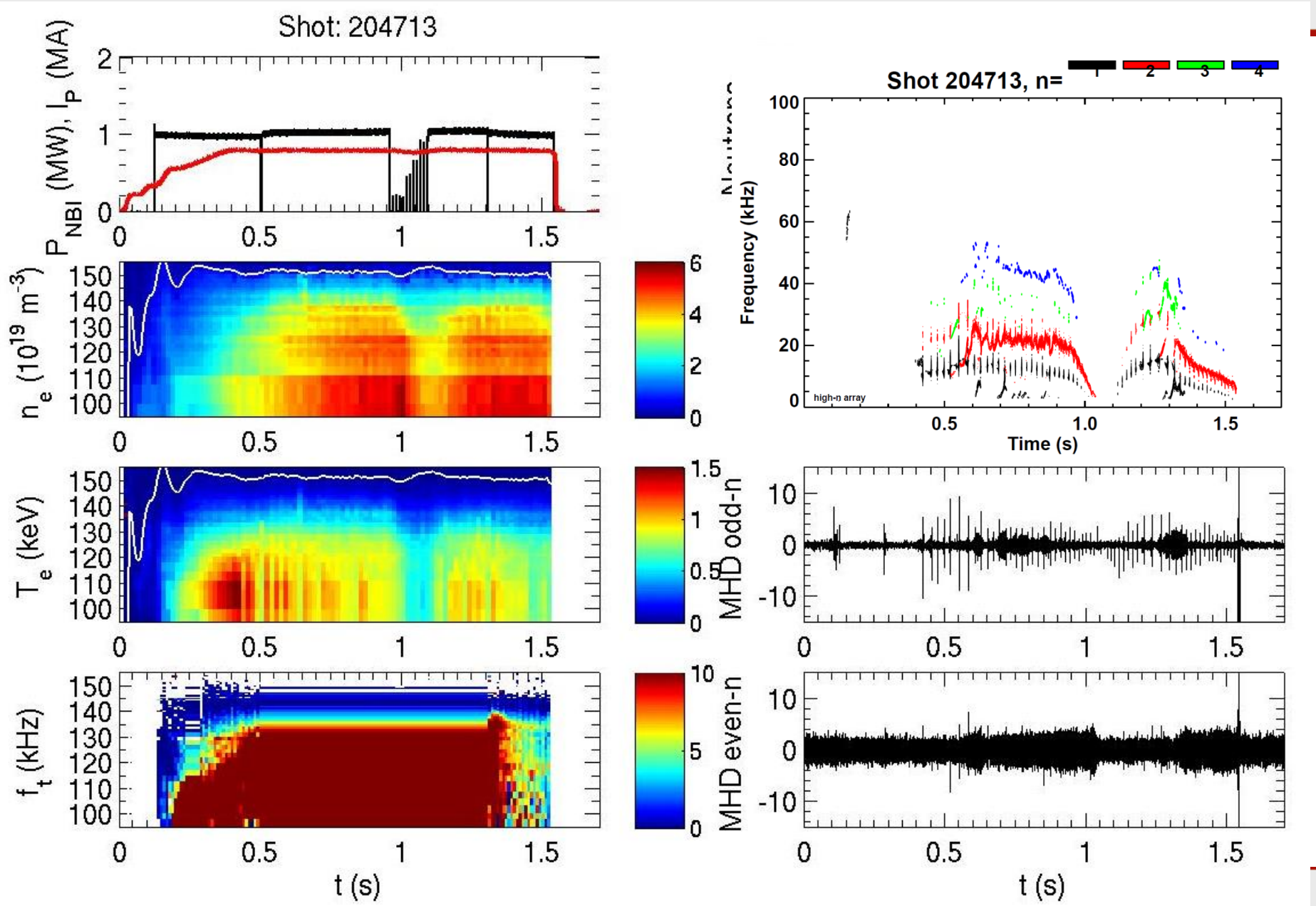
1B -> 2A


Shot: 204714
P_NBI (MW), I_P (MA)
n_e (10^19 m^-3)
T_e (keV)
f_t (kHz)
t (s)
Shot 204714, n=
1
2
3
4
Frequency (kHz)
high-n array
Time (s)
MHD odd-n
MHD even-n
t (s)

1B -> 2B

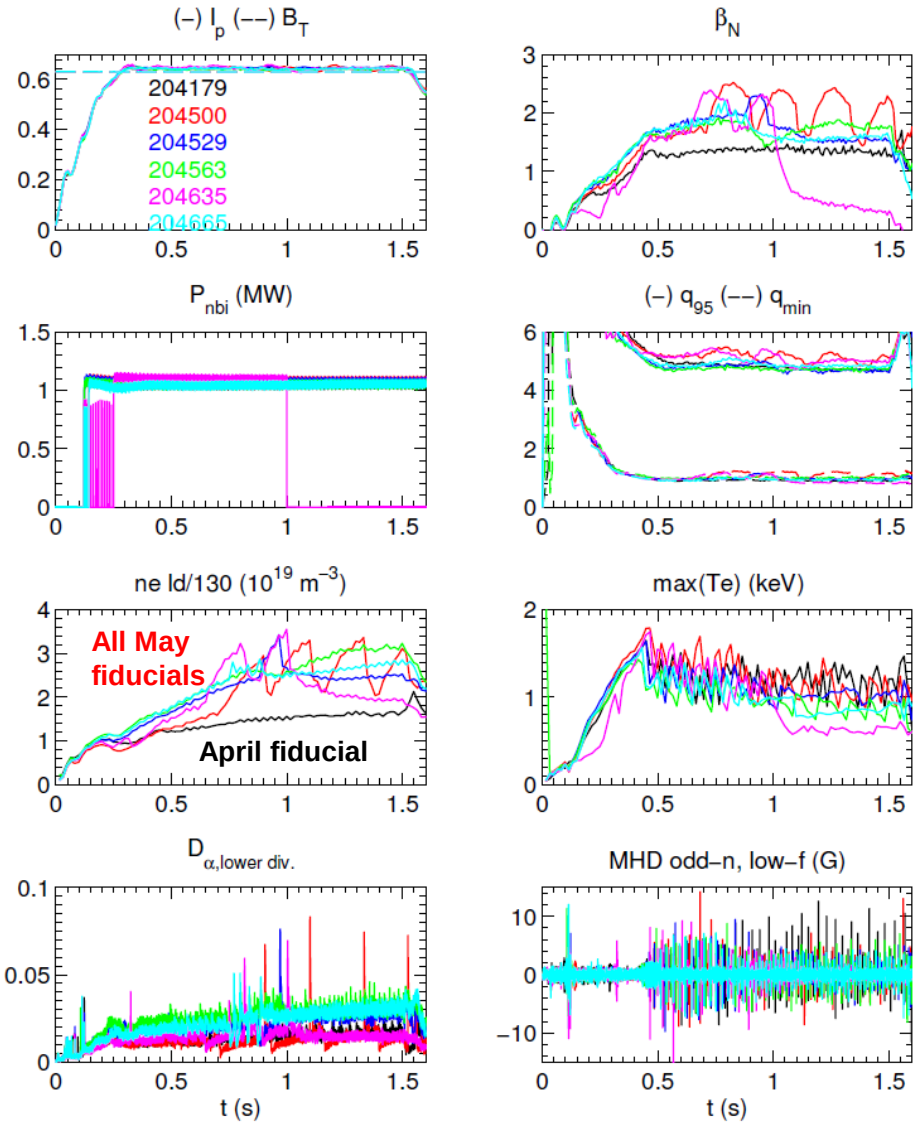

Shot: 204715
P_NBI (MW), I_P (MA)
n_e (10^19 m^-3)
T_e (keV)
f_t (kHz)
t (s)
Shot 204715, n=
1
2
3
4
Frequency (kHz)
high-n array
Time (s)
MHD odd-n
MHD even-n

1B -> 2C

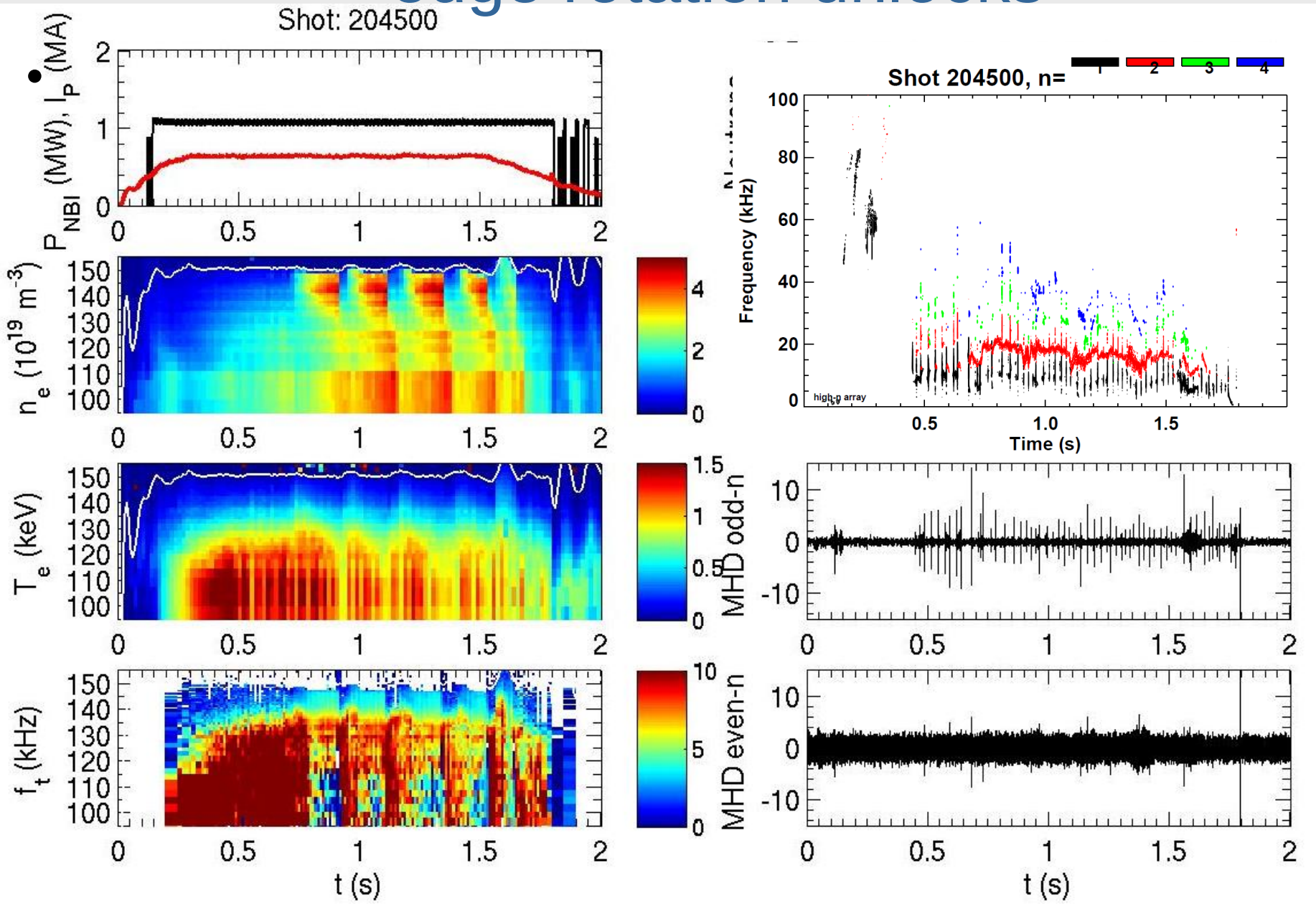

Shot: 204713
P_NBI (MW), I_P (MA)
n_e (10^19 m^-3)
T_e (keV)
f_t (kHz)
t (s)
Shot 204713, n=
1
2
3
4
Frequency (kHz)
high-n array
Time (s)
MHD odd-n
MHD even-n
t (s)

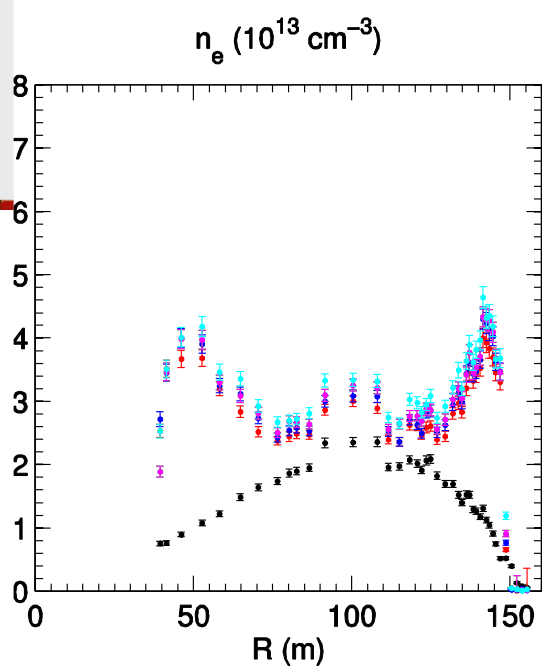
All May L-mode fiducials (204500+) exhibit L-H/H-L and/or n=2 MHD

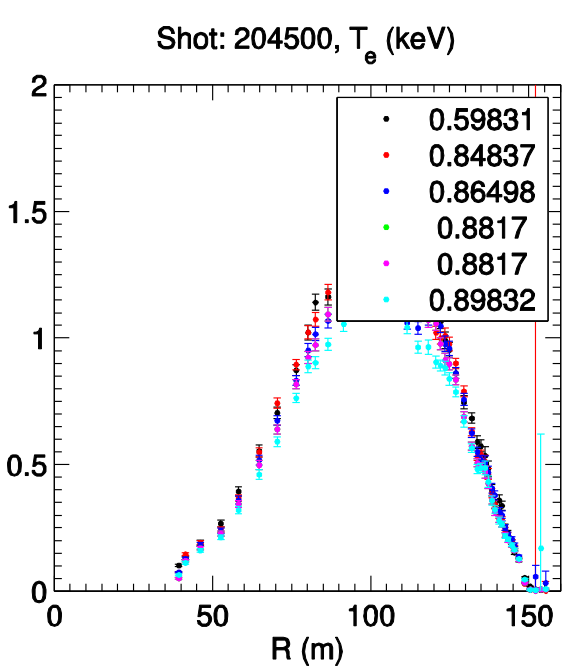
- 204179 was last fiducial prior to April 11-29 maintenance period
- All fiducials May 2-20 exhibited L-H/H-L transitions
  - Only showing fiducials with ~1 MW
  - A couple ohmic cases (missed beams) ran OK
- β_N, q_{95}, q_{min} from EFIT01 in these slides

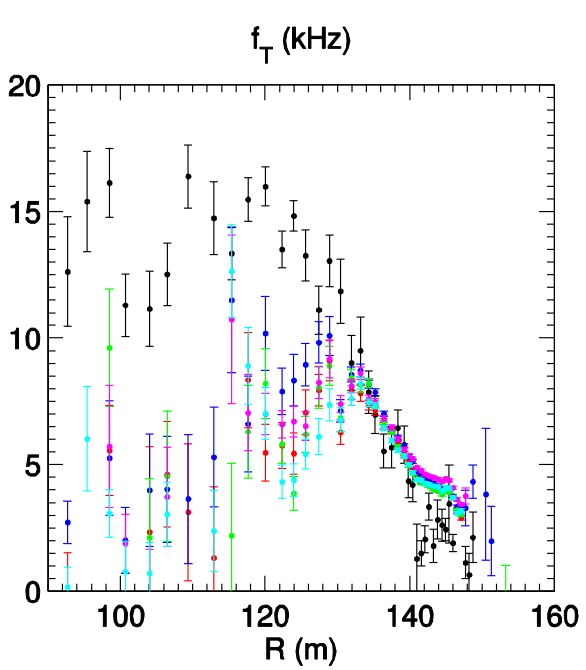


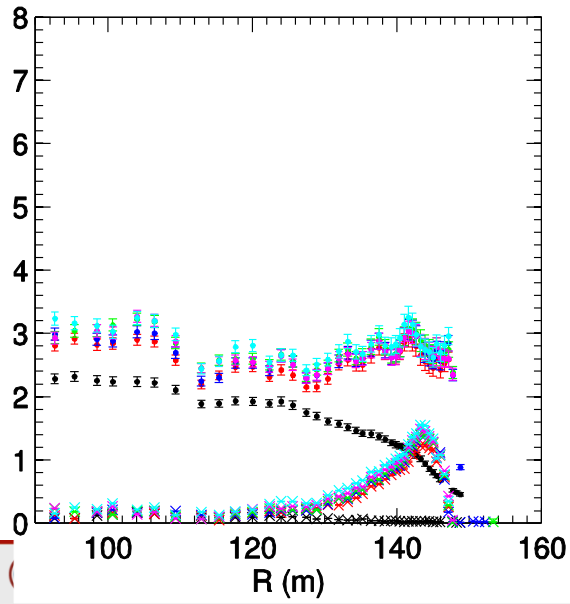
First May L-mode fiducial attempt at 4-5 L/H – edge rotation unlocks

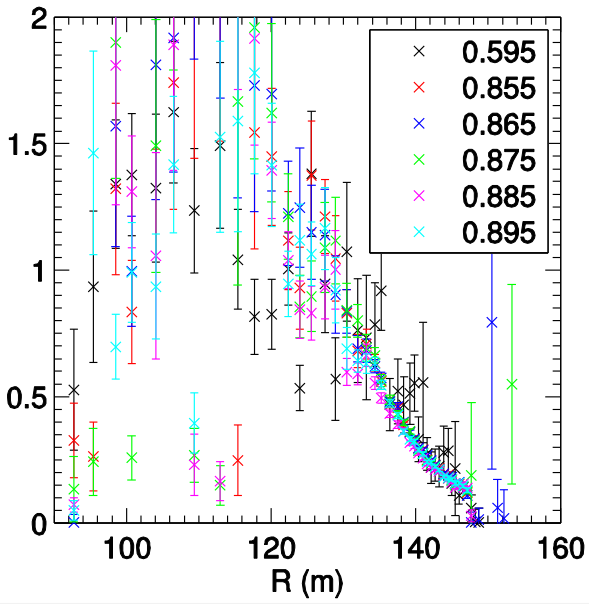


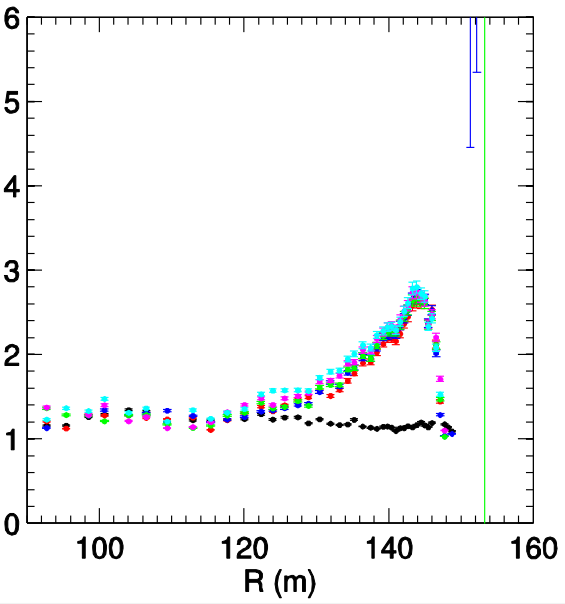

n_e (10^{13} cm^{-3})
R (m)


Shot: 204500, T_e (keV)
0.59831
0.84837
0.86498
0.8817
0.8817
0.89832
R (m)

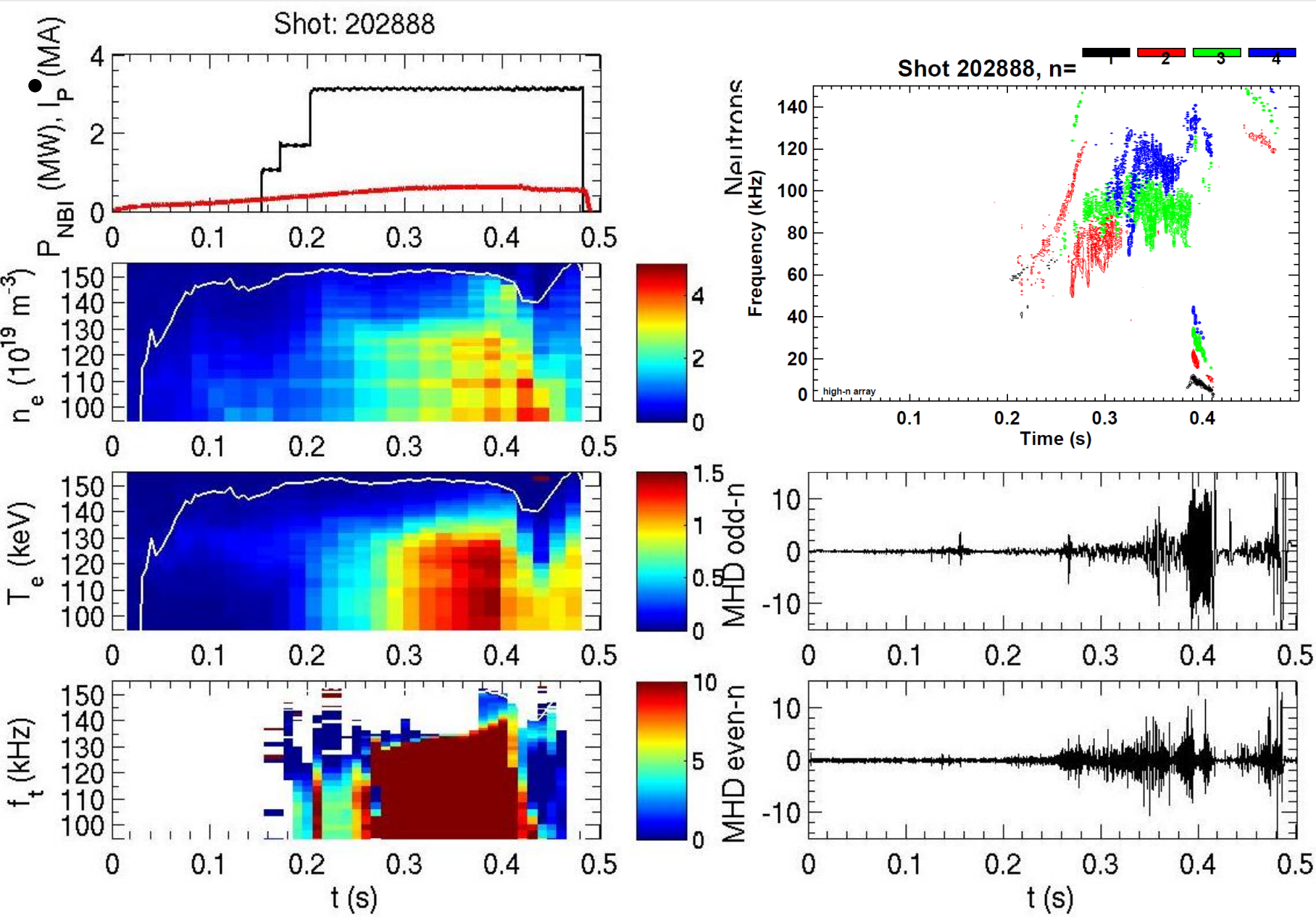

f_T (kHz)
R (m)

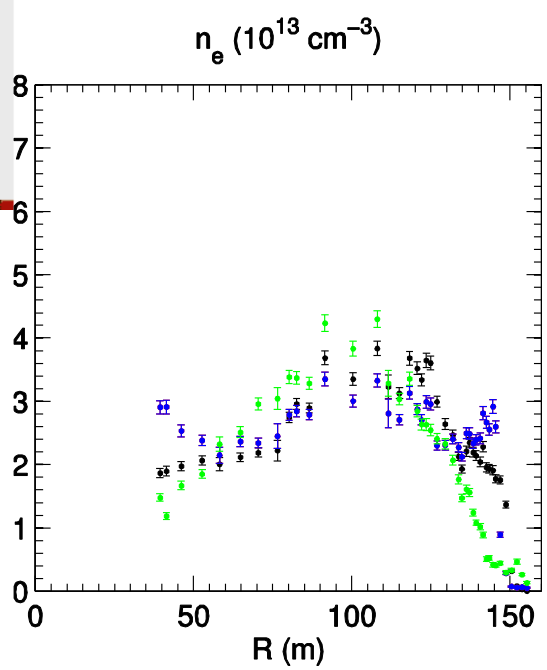

n_d (.), 6×n_c (x) (10^{13} cm^{-3})
R (m)

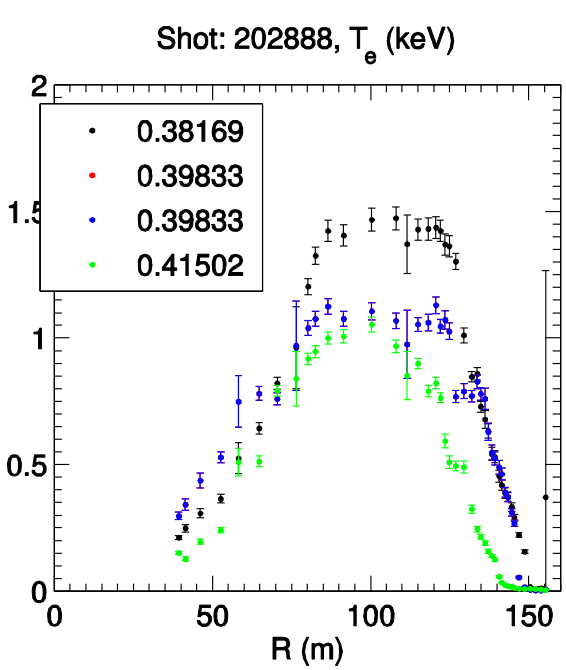

T_i (keV)
0.595
0.855
0.865
0.875
0.885
0.895
R (m)

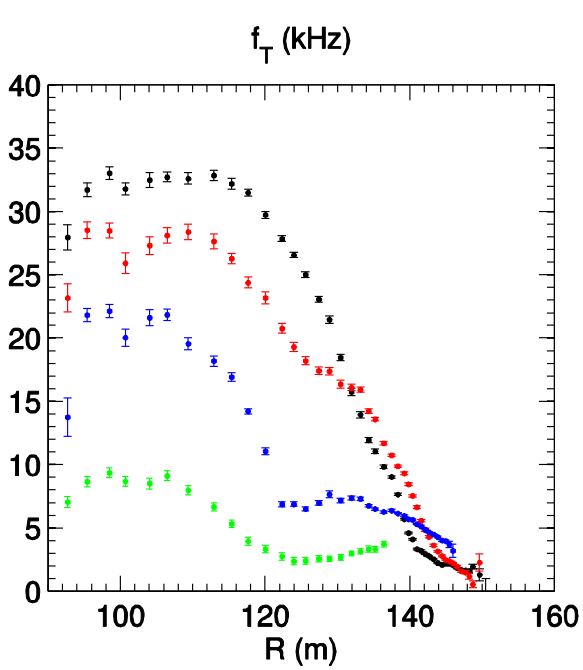

Z_{eff}
R (m)

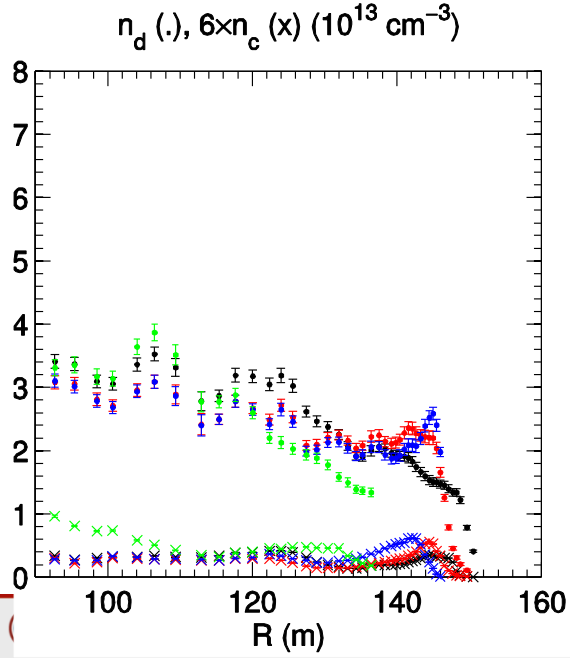
Example of unlocked edge rotation after L-H

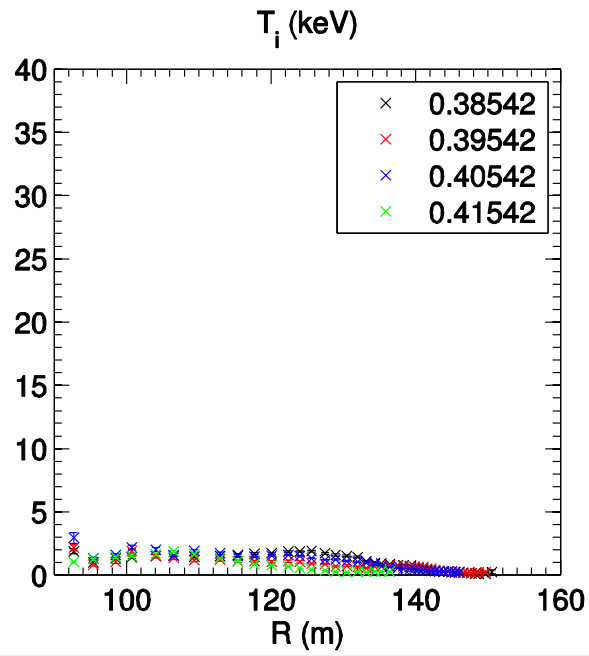


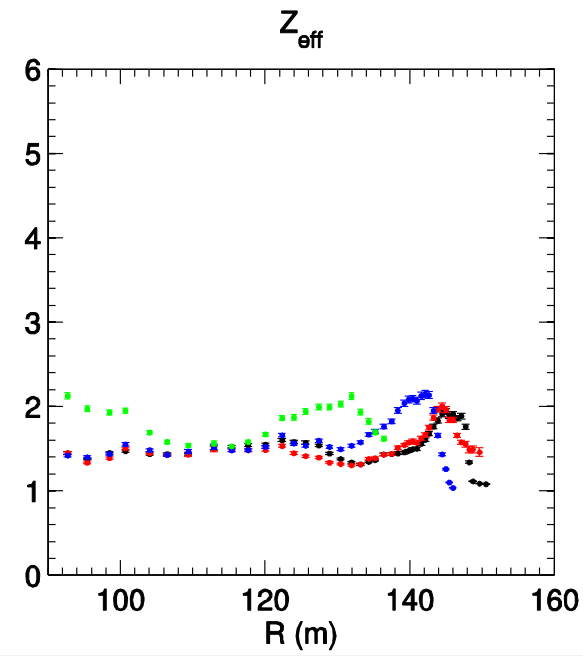

n_e (10^{13} cm^{-3})
R (m)


Shot: 202888, T_e (keV)
0.38169
0.39833
0.39833
0.41502
R (m)

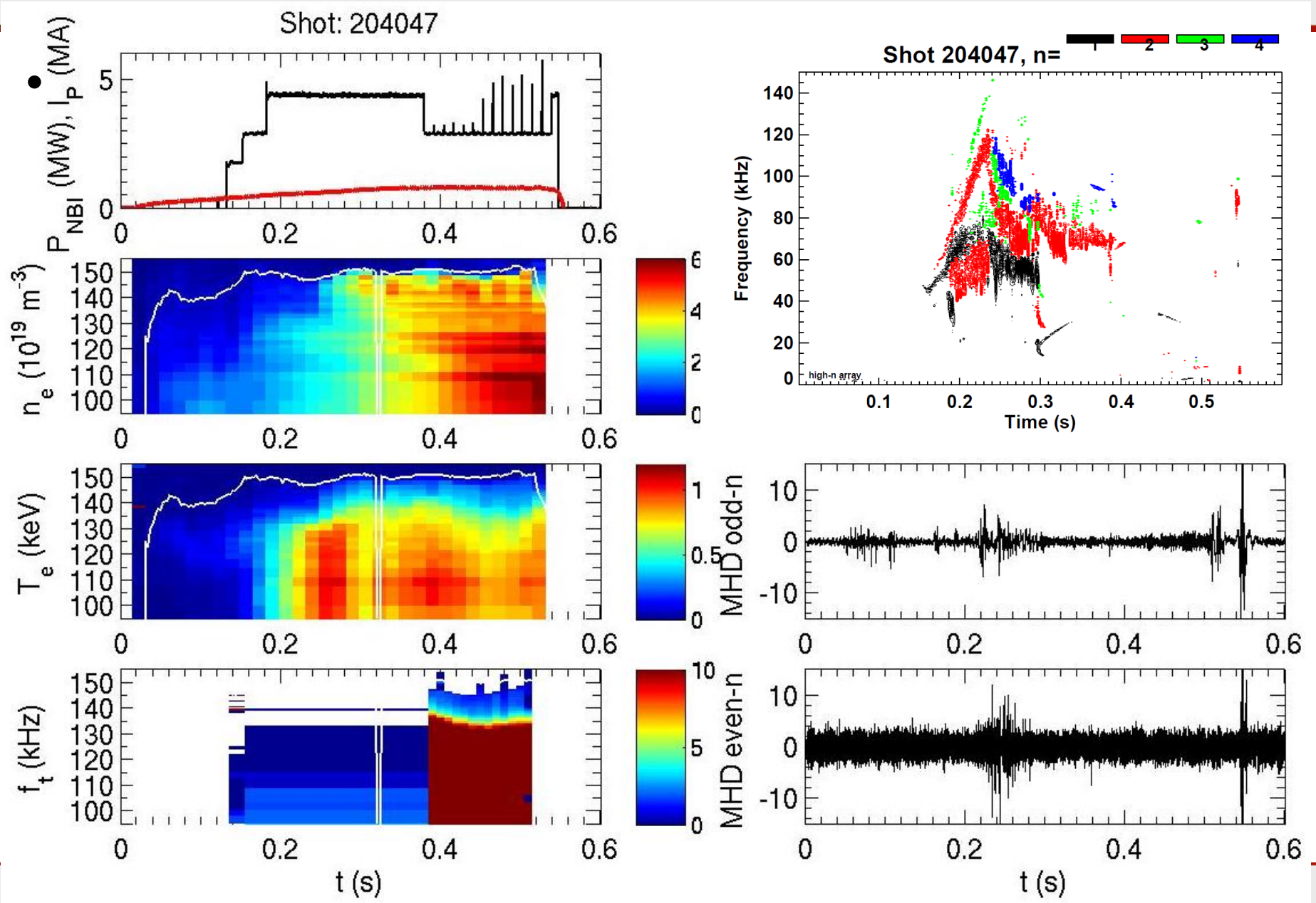

f_T (kHz)
R (m)

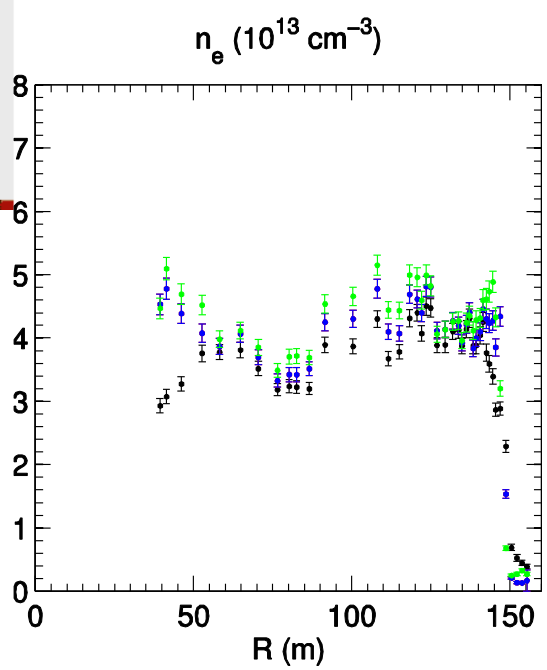

n_d (.), 6×n_c (x) (10^{13} cm^{-3})
R (m)

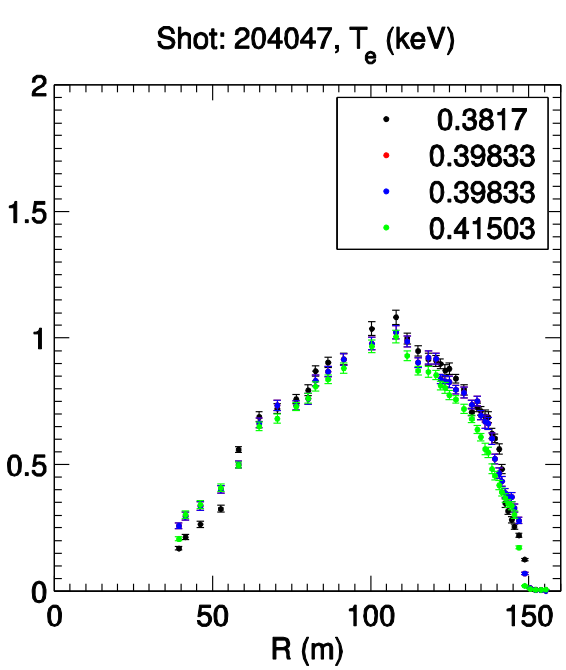

T_i (keV)
0.38542
0.39542
0.40542
0.41542
R (m)

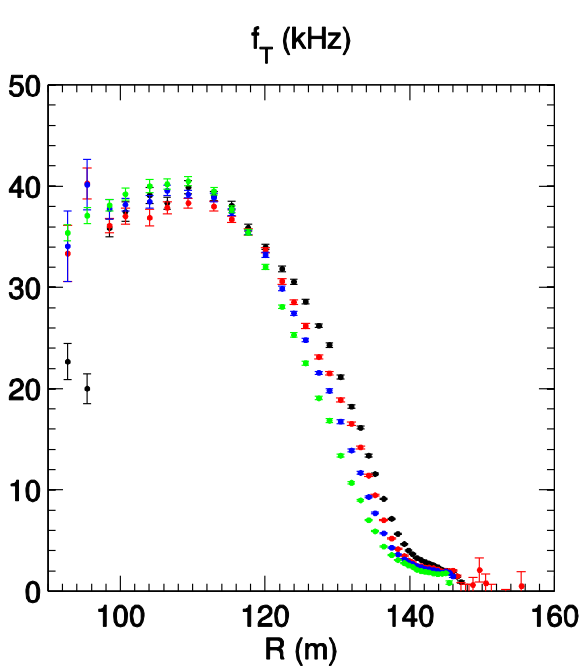

Z_{eff}
R (m)

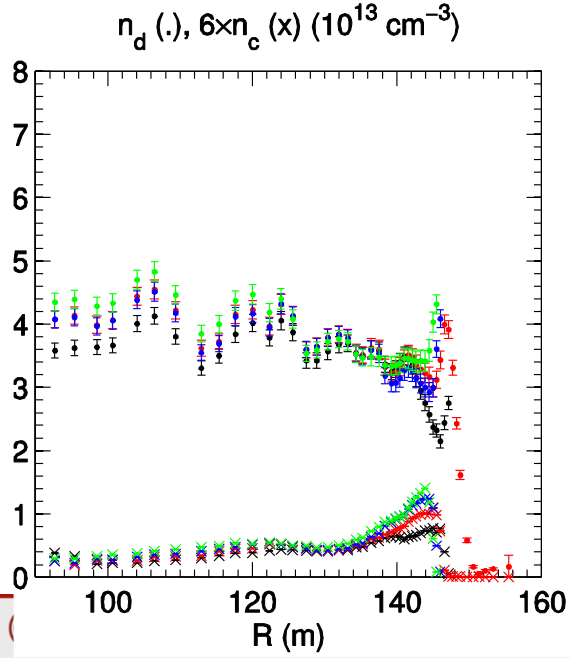
Unlocked edge rotation during H-mode

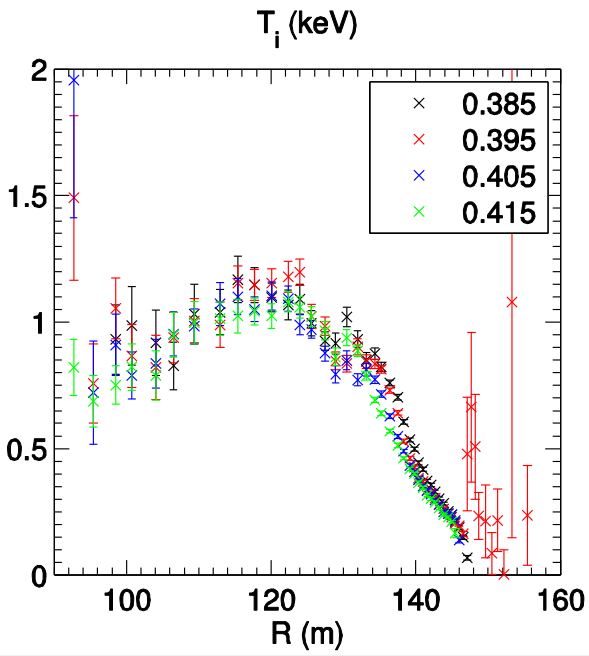


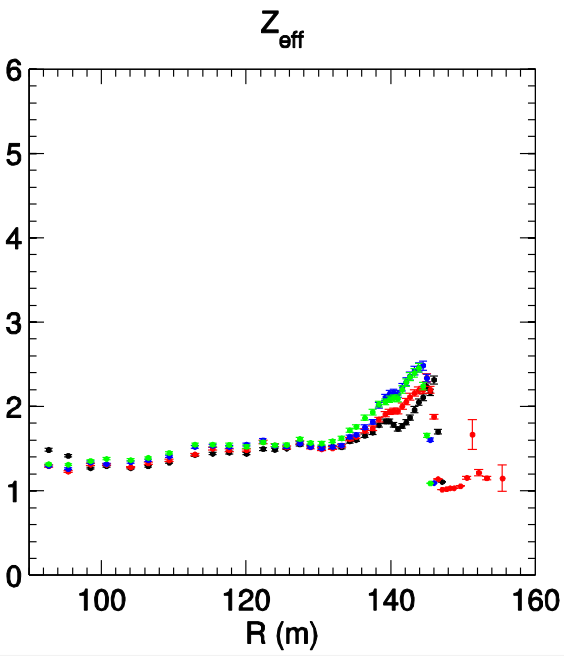

n_e (10^{13} cm^{-3})
R (m)


Shot: 204047, T_e (keV)
0.3817
0.39833
0.39833
0.41503
R (m)


f_T (kHz)
R (m)

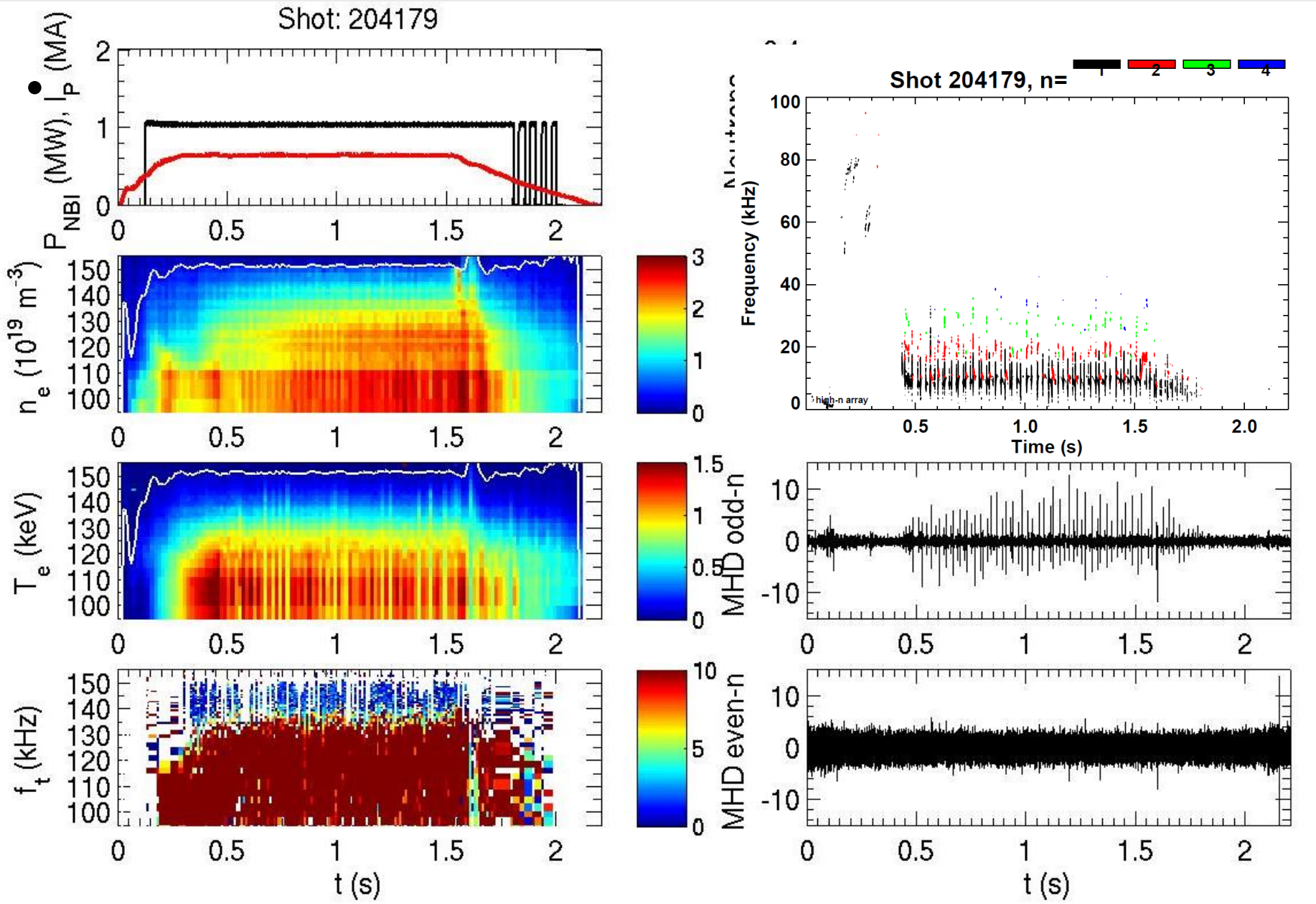

n_d (.), 6×n_c (x) (10^{13} cm^{-3})
R (m)


T_i (keV)
0.385
0.395
0.405
0.415
R (m)

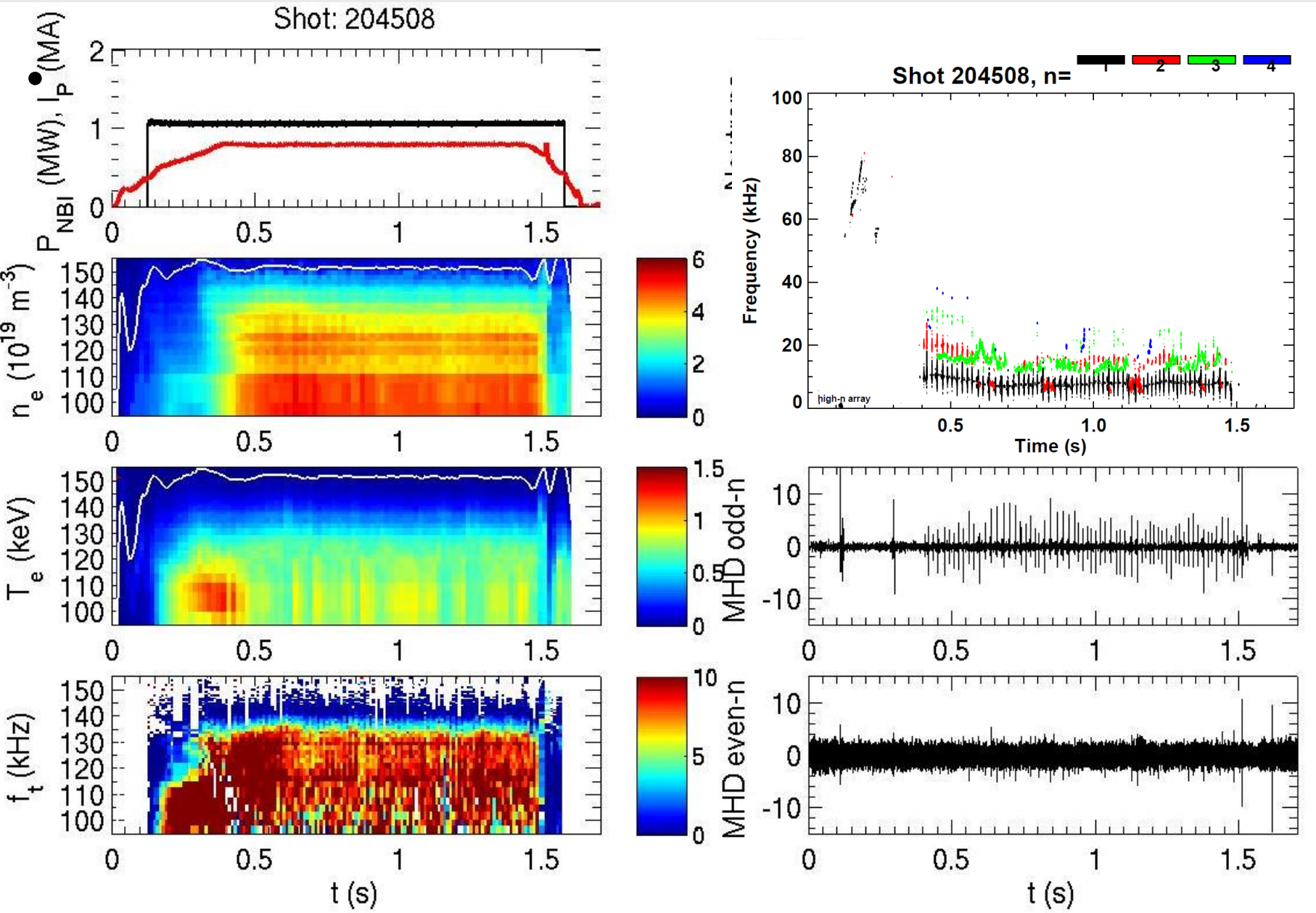

Z_{eff}
R (m)

BACKUP

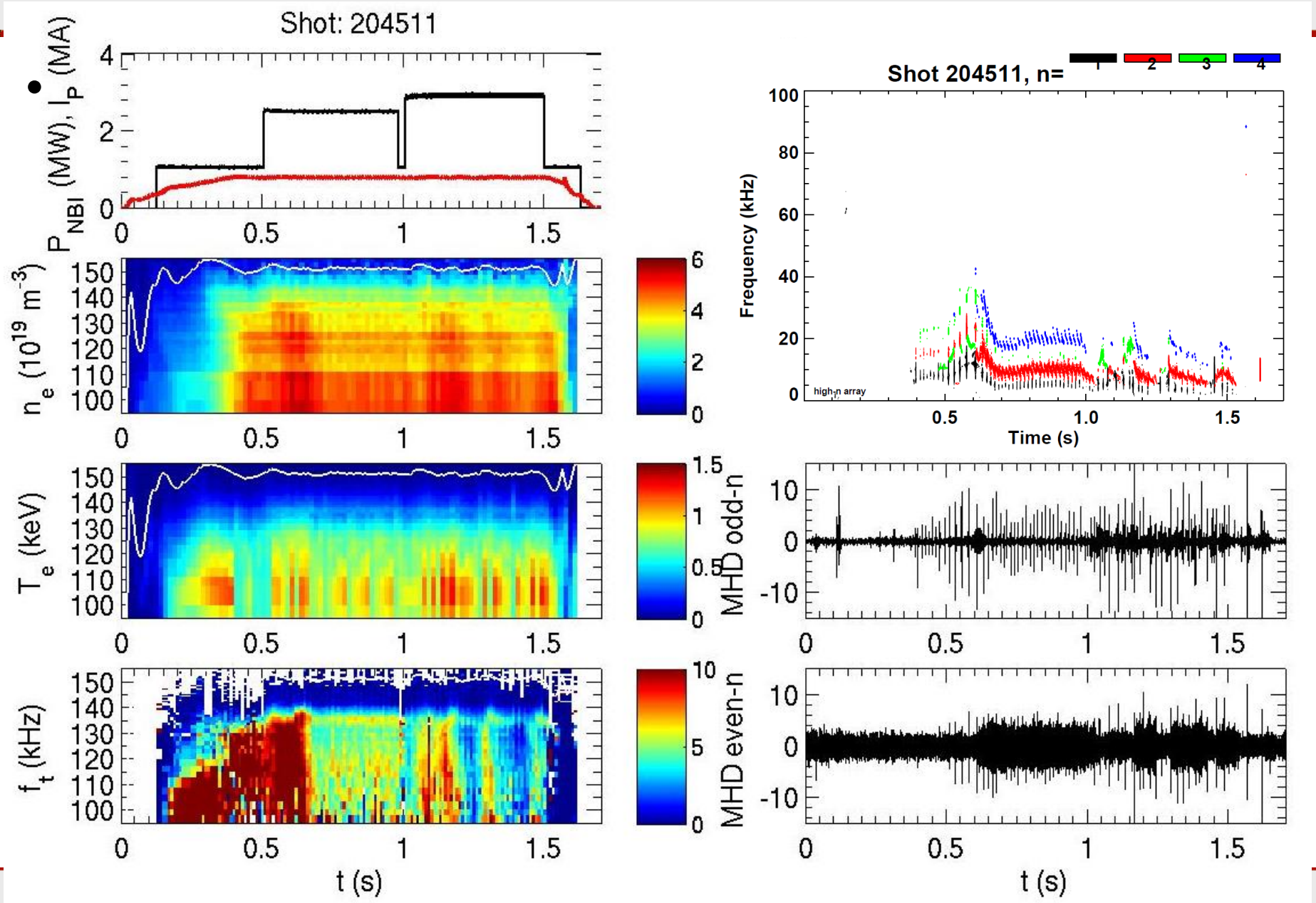
April L-mode fiducial



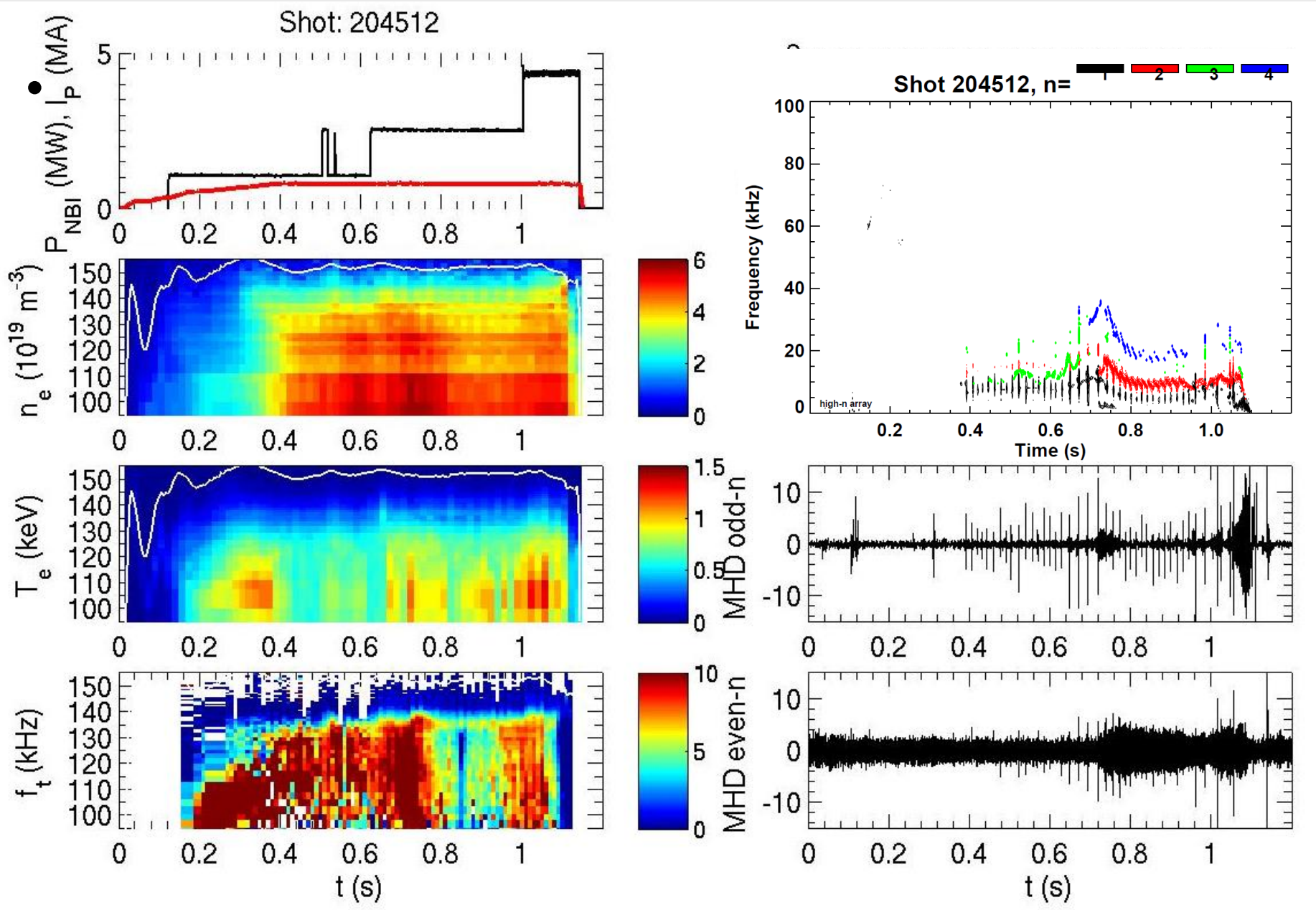
1 MW, 800 kA L-mode at higher density



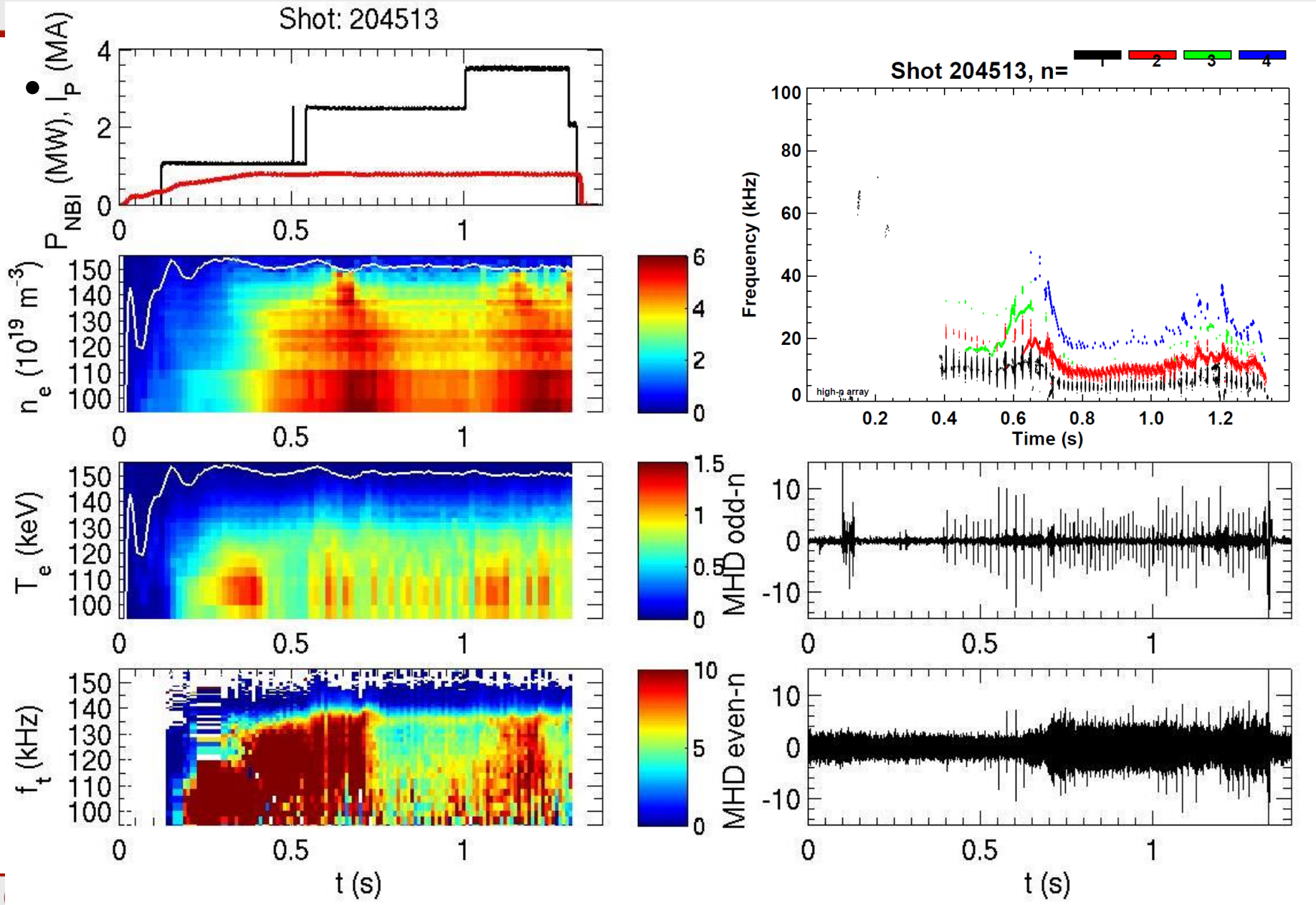
2.5 MW (1B+1A) - 2.9 MW (1B+1C) L-mode



4.3 MW L-mode (1B+1A+1C)



3.5 MW L-mode (1B+1A+1C)



Goal of XMP-151 is to establish expanded L-mode scenarios for core and boundary XPs

- Four parts of XMP based on desires expressed in meeting on April 4, 2016

1) Establish higher power L-mode
  - Achieved using HFS fueling + NBI 1 combinations
  - With more time, would try using LFS fueling (influence on inner wall "dancing rings" & MHD?)

2) Assess beam tangency radii

2A) Try individual sources (1 MW) shot-by-shot
  - Attempted, but unreliable fueling (L-H-L) and beams
  - Need to repeat

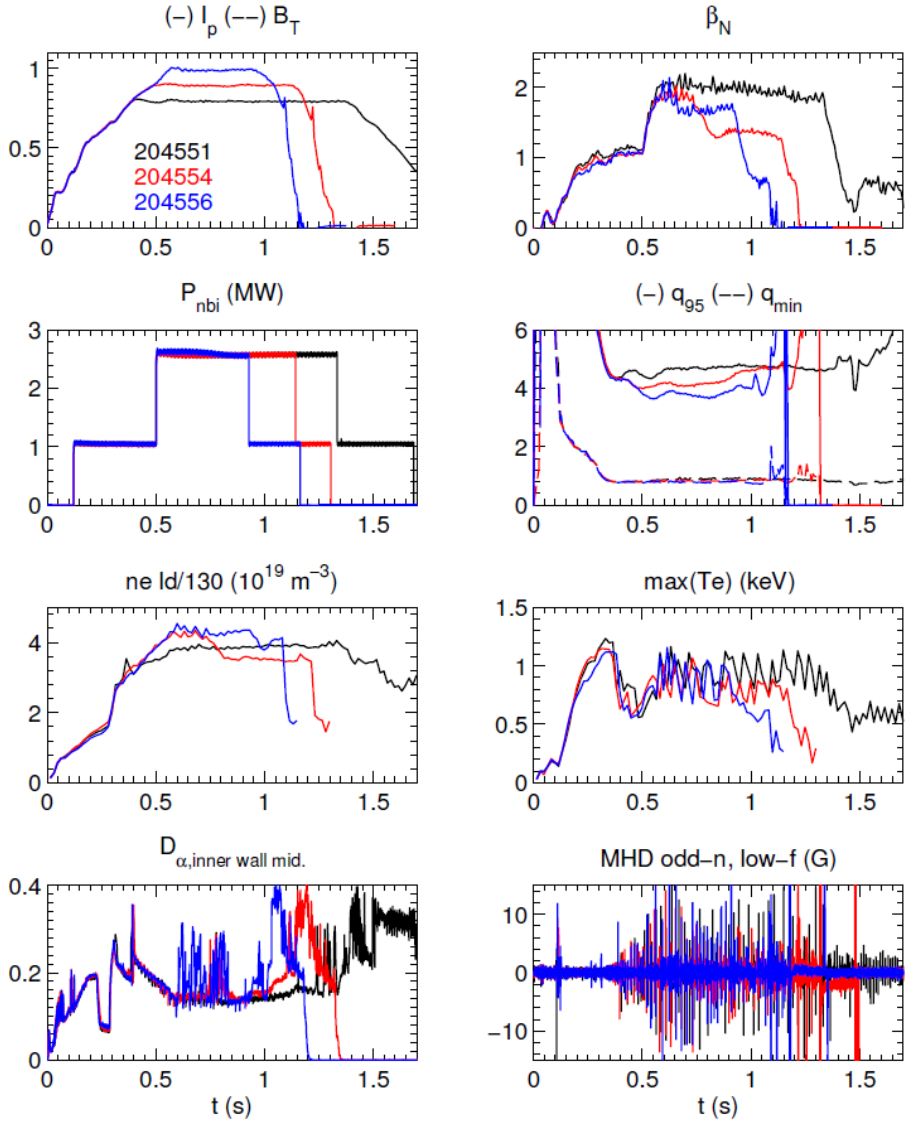
2B) Try 2-source combinations (~1+1 MW): peaked/broad, tan./perp.
  - Not done

3) Establish upper Ip limit
  - Achieved up to 1 MA
  - Have not demonstrated limit

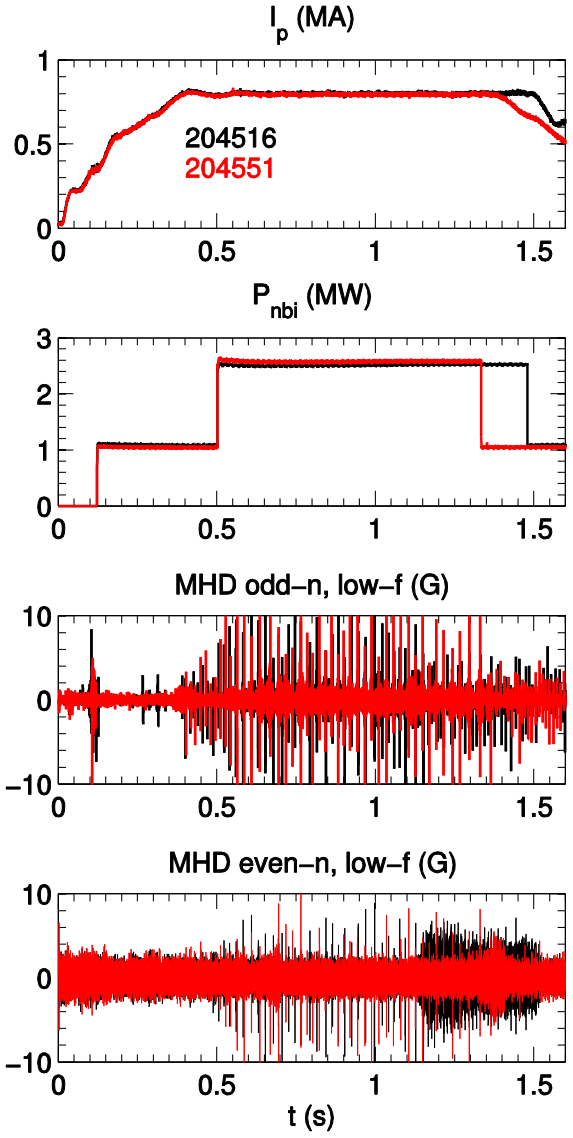
4) Establish lower BT scenarios (0.55, 0.45, 0.35 T)
  - Not done

Part 3 (5/6/2016): Was able to increase plasma current to 0.9 & 1.0 MA at higher density, fueling

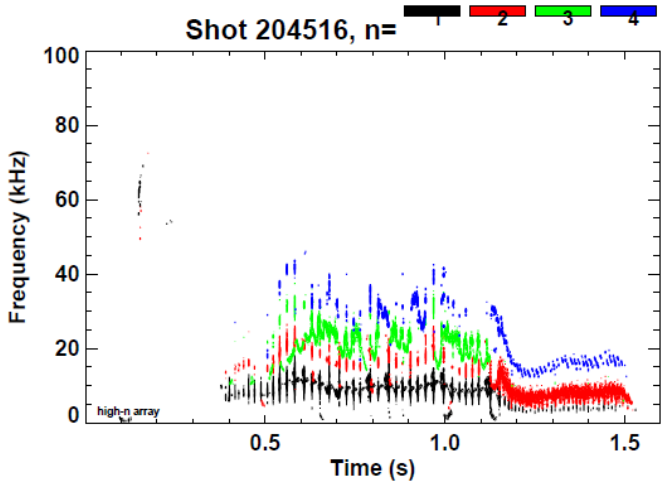
- To recover high density (following boronization & numerous short H-mode attempts) required HFS @ 1300 Torr for one shot
  - Returned to 900 Torr after
- Easily moved to 0.9 MA & 1.0 MA (q_{95}~3.7)
  - Did this in a couple shots at the end of a day - **would like to identify Ip limit**
- n=2 MHD always develops

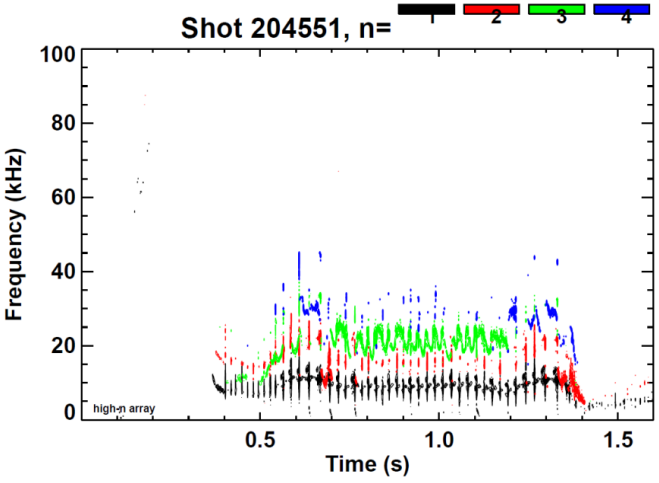


Otherwise duplicate 800 kA shots, 204516 develops n=2 earlier than 204551 (clamps core rotation and density)



- Strong n=2 often develops after L-H-L





Some of my favorite XMP-151 shots

- (5/5/2016) 800 kA w/ increased HFS fueling & power
  - 204499-507 – fiducial, then increased fueling to prevent H-mode
  - **204508 – 1 MW, 1B (0.12 s), lasts >1.5 s (3×10^{19} m^{-3})**
  - **204510 – 2.5 MW, 1B+1A (0.5-1.15 s)**
  - **204511 – 2.5 MW, 1B+1A (0.5-0.98 s), 2.9 MW, 1B+1C (1-1.5 s)**
  - 204512-515 – 3.5-4.3 MW attempts (1A+1B+1C) that die from H-mode/MHD
  - **204516 – 2.5 MW, 1B+1A (0.5-1.5 s)**
  - **204519 – 1A (0.12), 1B (0.5 s), lost 1A early (0.6 s)**

- (5/6/2016) 0.8, 0.9, 1.0 MA (1B, 1.1 MW, 0.12 s + 1A, 1.5 MW, 0.5 s)
  - 204547-550 – increase fueling to establish density & prevent H-mode
  - **204551 – 800 kA (ST → n=2 MHD @ 1.35 s)**
  - **204554 – 900 kA (ST → n=2 MHD @ 0.68 s???)**
  - **204556 – 1.0 MA (ST → n=2 MHD @ 0.9 s, after 1A turn-off)**

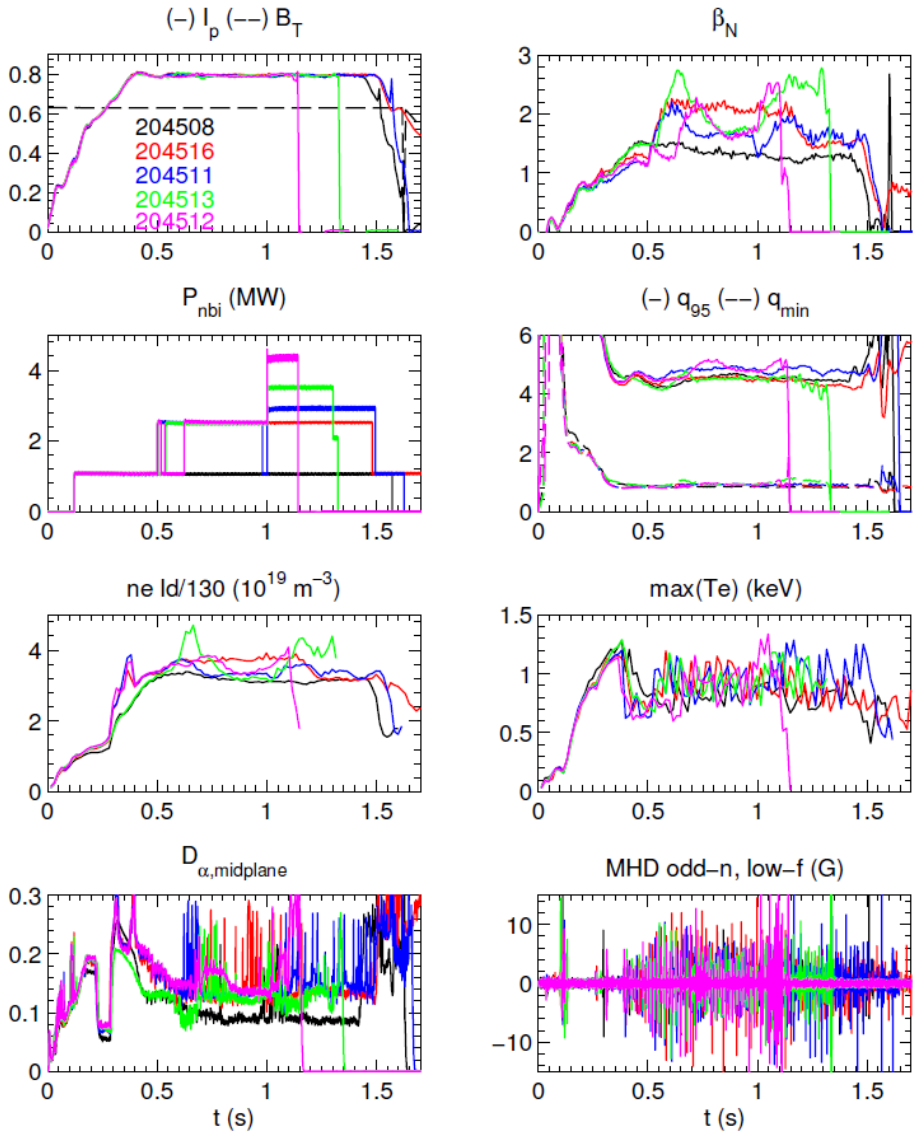
Some of my favorite XMP-151 shots

- (5/13/2016) 800 kA, 1 beam (1 MW) tangency scan
  - 204709 – 1C (1 MW), first shot, n=3 (2 kA), t>1.0 s (L-H-L, MHD, slow vert. osc.)
  - 204710 – 1C (1 MW), long shot but no SPAs

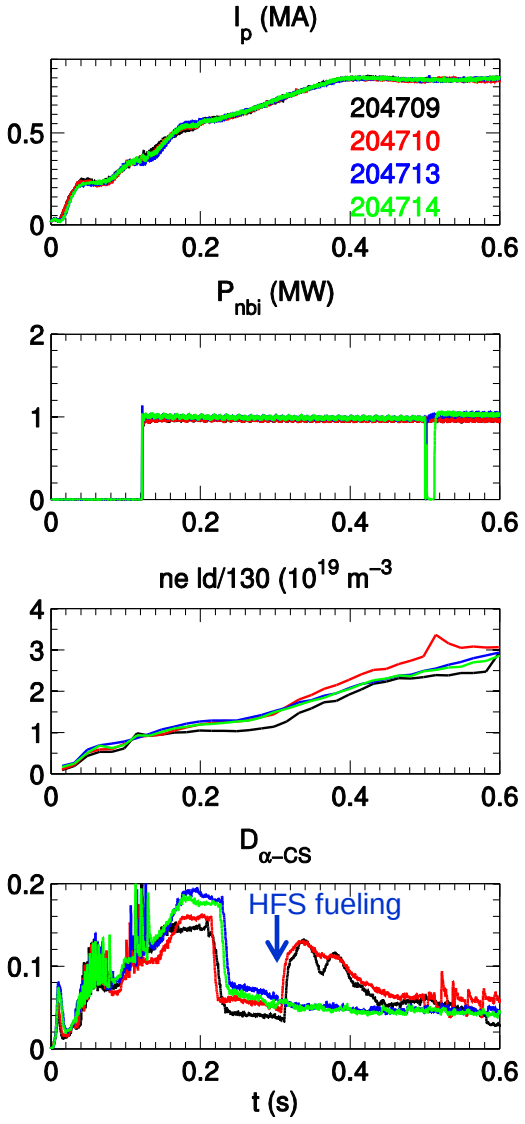
  - Following shots use 1B t<0.5 s & t>1.3 s, swap source between 0.5-1.3s
    - Also had very weak HFS fueling due to gas pressure reading issue, issues with L-H-L, vert. osc.
  - 204713 – 2C (drops out 0.95-1.09 s)
  - 204714 – 2A (ends at 650 ms from locked mode)
  - 204715 – 2B (good, 1 L-H-L at 520 ms)
  - 204716 – 1A (good, 2 L-H-L)
  - 204717 – 1C (good, 1 L-H-L)
  - 204718 – 1B (good, L-H-L, vert. osc. that slowly grows)
    - Finally realized we were getting almost no additional fueling
  - 204719 – 1B – higher fueling, too much, cools edge, plasma dies

(5/5/2016) Many shots testing increased power up to 4.3 MW

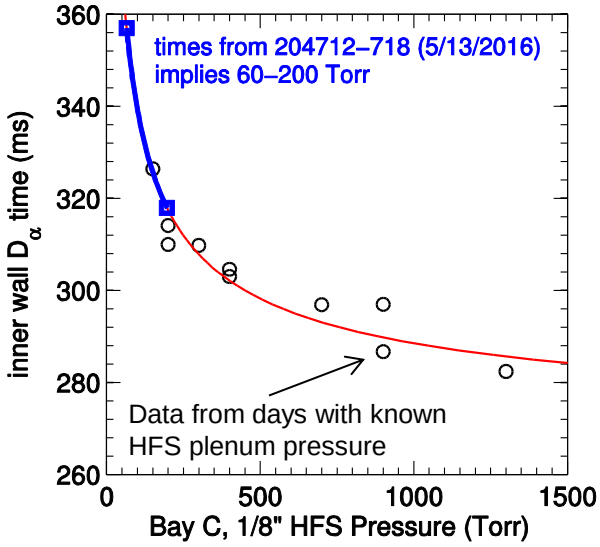
- Many shots to vary NBI 1 power
  - 2.5 (1B+1A & reversed order)
  - 2.9 MW (1B+1C)
  - 3.5-4.3 MW (1B+1A+1C) – too high to avoid H-mode and/or shot-ending MHD
- Crazy MARFE-like “dancing rings” (D. Battaglia) observed in innerwall midplane spectroscopy (D_α, O2, C2)
- Drop in n_e, β_N often seen due to transition from sawteeth to n=2 MHD (e.g ~1.2 s in 204516)

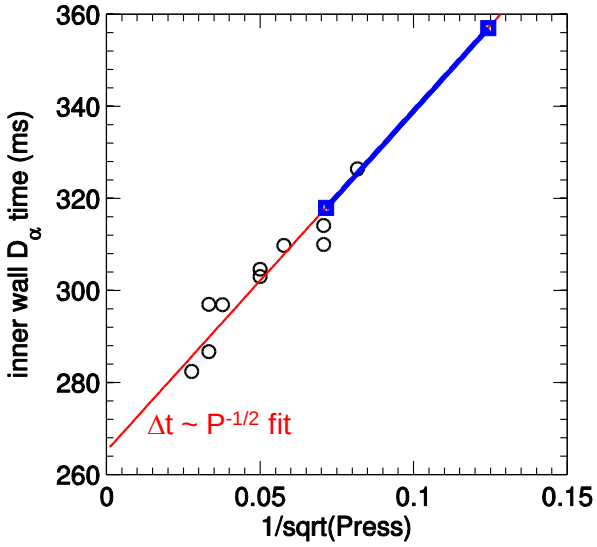


Late Friday afternoon (5/13) it was observed that HFS plenum pressure reading was no longer accurate



- 204710 – FPDP Watchdog timer tripped at end of shot
- 204711-712 – no shots (didn't reset FOMS; clock cycle)
- 204713-718 → faulty HFS pressure reading
  - Fueling very late & weak based on plasma TV & EIES inner wall D_α
- Using data from previous days, fit $\Delta t_{D\alpha\text{-}CS} \sim 1/P_{HFS}^{1/2}$ – implies HFS pressures between 60-200 Torr for rest of Friday afternoon (we were requesting 400 Torr)
  - This is based on requested pressure in the Logbook, no measurement signal available in MDSplus?





- All L-modes have exhibited sawteeth, strength varies with density, beam source(?)
- Many/most of the discharges with ≥1 MW develop strong n=2 MHD
- Related XMP-119 (Ren, L-mode validation) aims to establish “MHD quiescent” L-mode at 2 MW from NBI 1A