XP 834: Threshold and Small Island Physics of the 3/2 NTM

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Helpful discussions with E. Fredrickson, R. Buttery, R. LaHaye

Goals of the XP

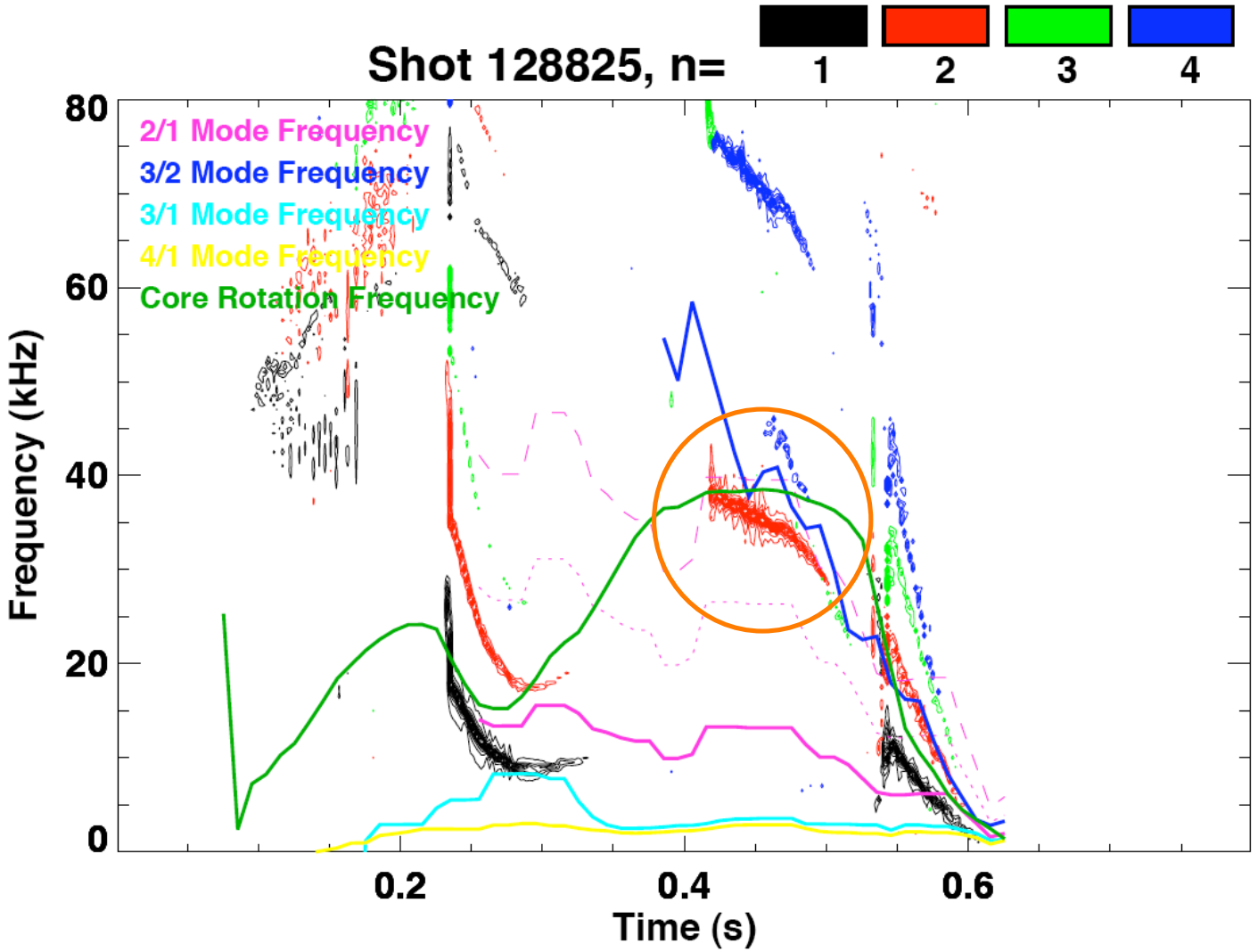
- Recreate a newly “discovered” method to trigger a 3/2 NTM.
  - First time SPG is aware of a reliable recipe for triggering mode in NSTX.
- Use NBI ramp-down to decrease beta and restabilize the mode.
  - Information on the small island physics available during rampdown.
  - Data can be directly compared to results from conventional aspect ratio.
  - ***Key component of the XP***
- Use n=3 braking in order to study the effects of plasma rotation and rotation shear on saturated island width and small island physics.
  - Important for projecting to plasma with minimal momentum input.
- Study the “recipe”
  - What is the role of delayed H-mode and the “beam trigger“?

Observations of 3/2 NTM in NSTX

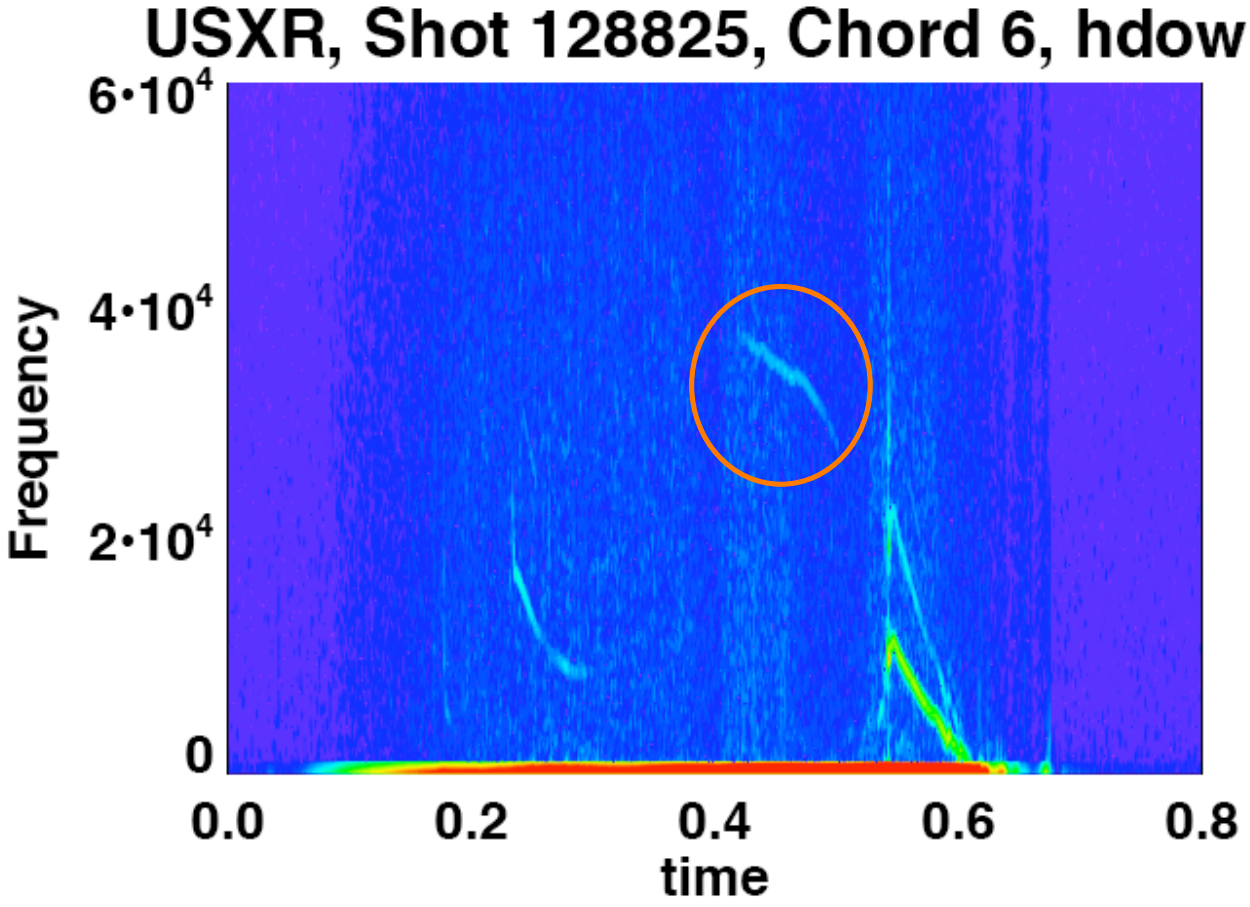
What is the recipe?

- Recipe (found in a beam modulated Ion Power Balance Experiment):
  - 15 minute shot cycle, 1 minute D_2 glow, followed by 8 minutes He glow.
    - Delays the H-mode to ~230 msec (i.e. end of the current ramp).
  - Step a beam source on (or 1 off, followed by 2 on).
    - Apparently generates a seed island.

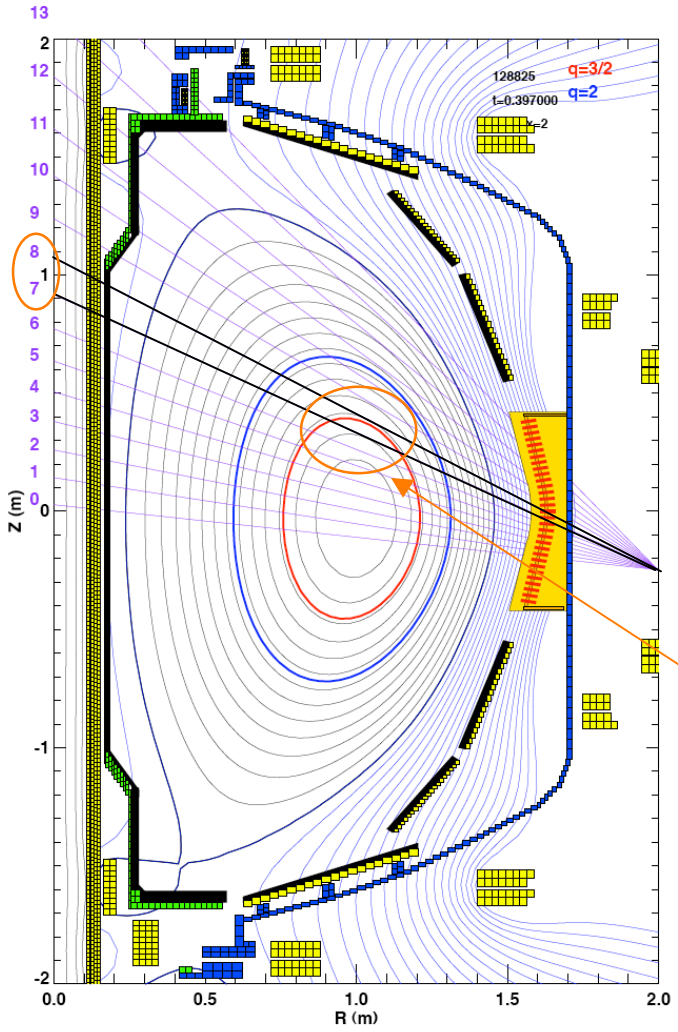
We have a Recipe For Generating 3/2 modes

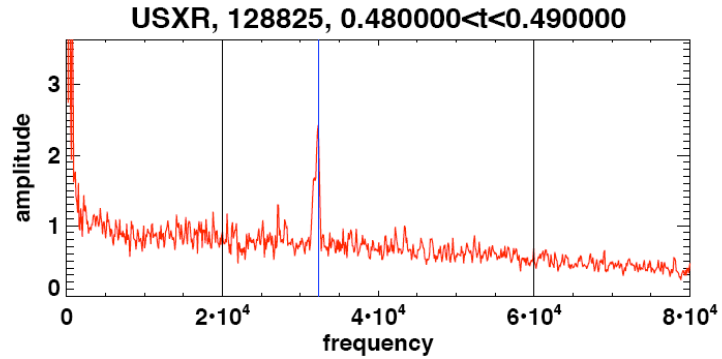


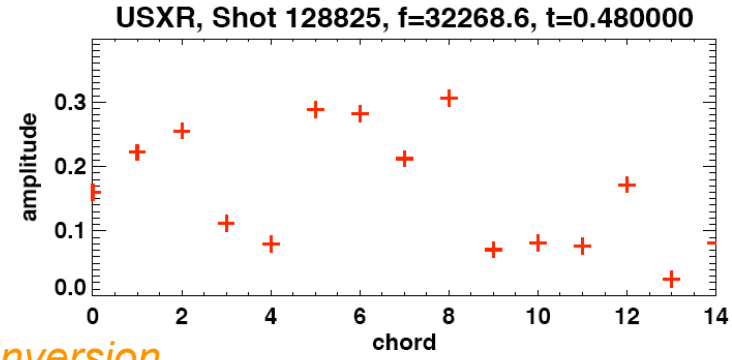
Mode Weekly Visible With the USXR System



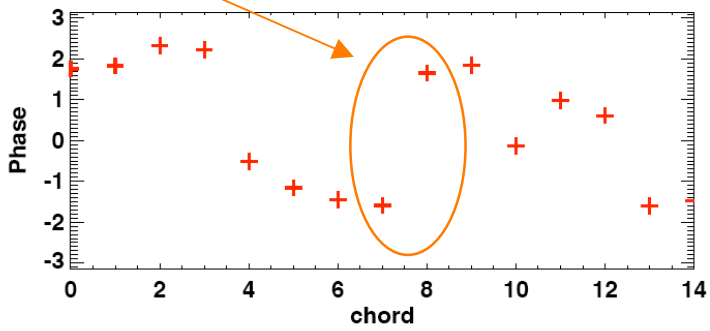
USXR Inversion Radius at 3/2 Surface



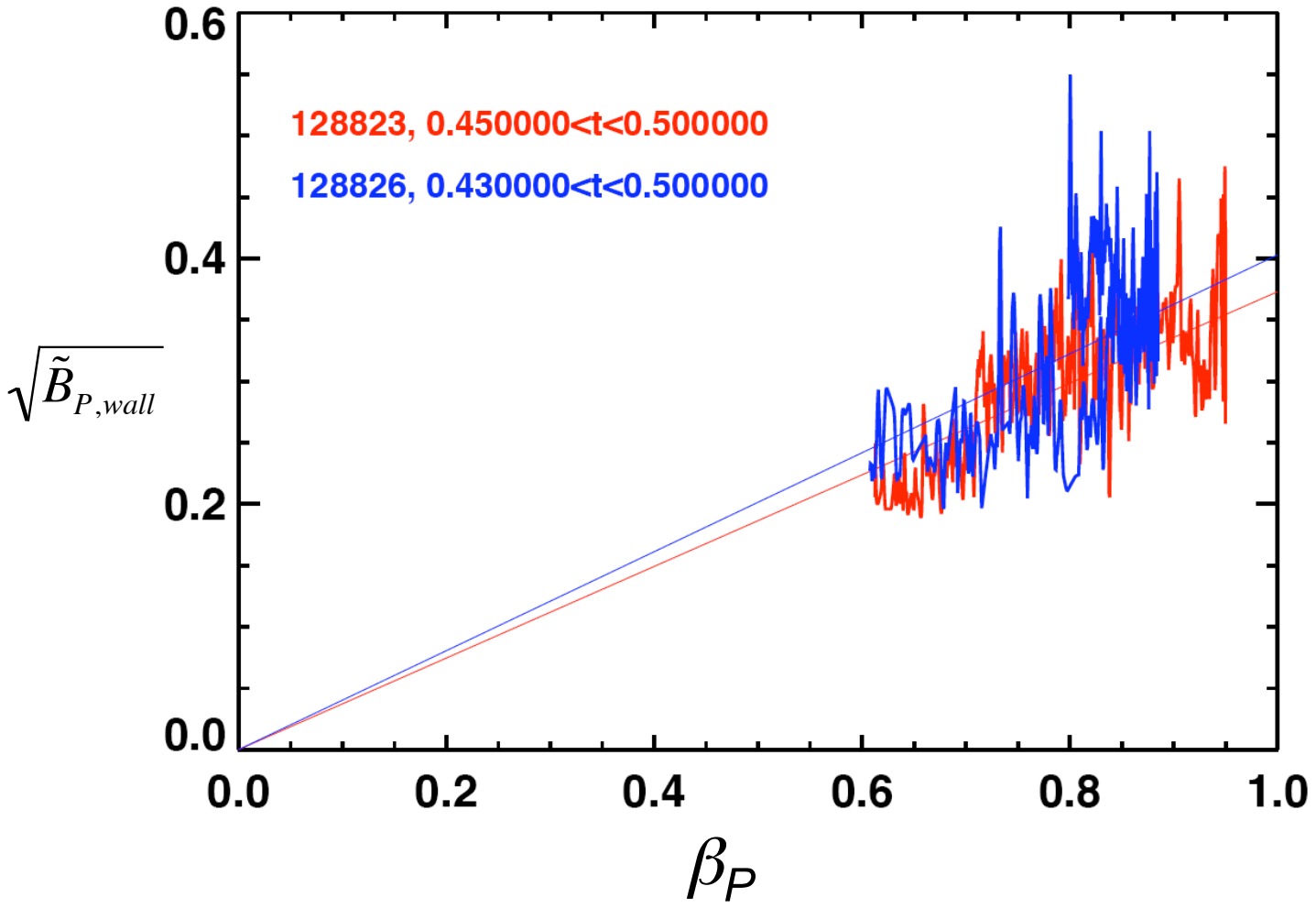




Phase Inversion



Mode Has NTM-like Beta Dependence



Physics Elements of the XP

Need a Measure of the Island Width

Flat-spot not usually seen on TS or CHERS for 3/2 mode, no ECE

Mirnovs:

- Signal is clear on outboard, but very weak on the inboard poloidal array.
- Have synchronized poloidal array now, and bad digitizer replaced yesterday.
- Rely on the PPP & SPP Mirnovs for island width calculation, in conjunction with “absolute calibration” using island models.
- I have made some progress here…

USXR:

- Would like a 10μm and 100μm filter to start with.
- Rely on inversion techniques and island models.
- I have made some progress here.

Both tools need further development, but show promise

- Last night, Charles Bush suggested using FAST Soft X-ray Imaging Camera…great!

Want to Study Restabilization

Most important part of XP.

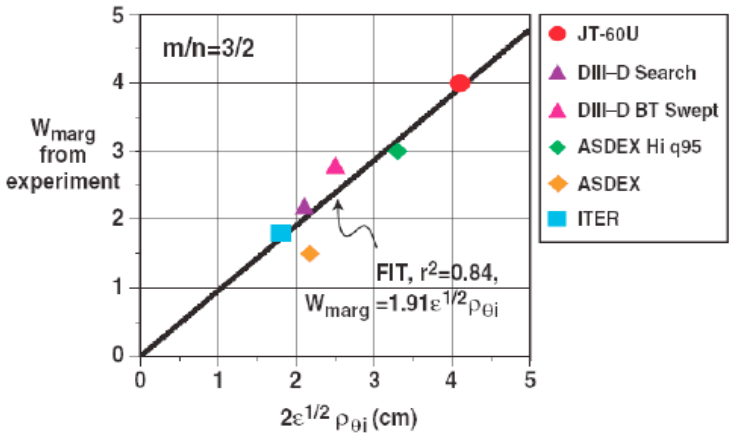
- Step NBI power down after mode strikes, in order to restabilize the mode and measure the marginal island width.
- Potential problems:
  - Loose H-mode before restabilization.
  - Plasma slows and locks.
  - m/n=2/1 mode strikes (will be included in 2/1 mode database ☺).
  - From P.W. Ross day, rapid equilibrium changes can make reconstruction difficult.
- Do this for three plasma currents at fixed q.
- Typical result for marginal island width:

$$w_{m\,\arg} \sim \rho_{\theta,i} = \frac{2\times10^{-4}\sqrt{T_i(eV)}}{B_\theta}$$

$$w_{m\,\arg} \sim \rho_{\theta,i} = \frac{2\times10^{-4}\sqrt{(T_i = 600)}}{(B_\theta = 0.15)} = 3cm$$

$$2\sqrt{\varepsilon}\rho_{\theta,i} = 2\cdot\sqrt{\frac{0.2}{1}}\cdot 3 = 2.7cm$$

Data From R. Buttery, APS 2007



Also Would Like to Study Dependence on Rotation

- Reactor won't have external momentum input, and may not rotate quickly.

- DIII-D shows smaller islands with increased rotation shear. (LaHaye, NSTX Monday physics meeting)

- Trend with rotation already observed for 2/1 onset beta in NSTX (slower plasma trigger more easily).

- For 3/2 mode with n=3 braking, look at
  - Saturated island width at fixed β_{Pe}.
  - Study marginal island width at fixed B_P, T_i.

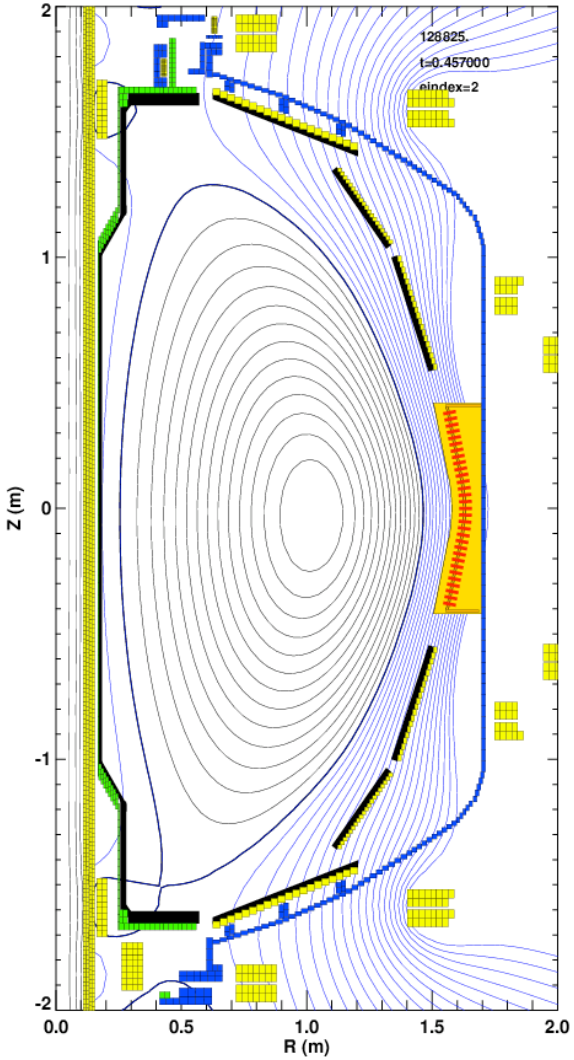
- If a trend is found, establish if it is rotation or rotation shear.

Detailed Plan of the XP

Step 1: Establish Reference Configuration With Mode (5 shots)

- Shot 128825, PF1A shot
- I_P=900kA
- κ=2.25
- dr_{sep}=-0.7 cm
- δ_l=0.75 , δ_u=0.45
- Outer Gap: 10cm
- I_{TF}=-53 kA
- Voltages [A,B,C]=[90,80,90] kV

- 1 minute D_2 glow, followed by 7 1/2 minutes of He, 15 minute shot cycle.
- Turn on A at t=0.05 and C at t=0.08
- @ t=0.39, turn off Source B
- @ t=0.4, turn on B & C
- @ t=0.41, turn off C



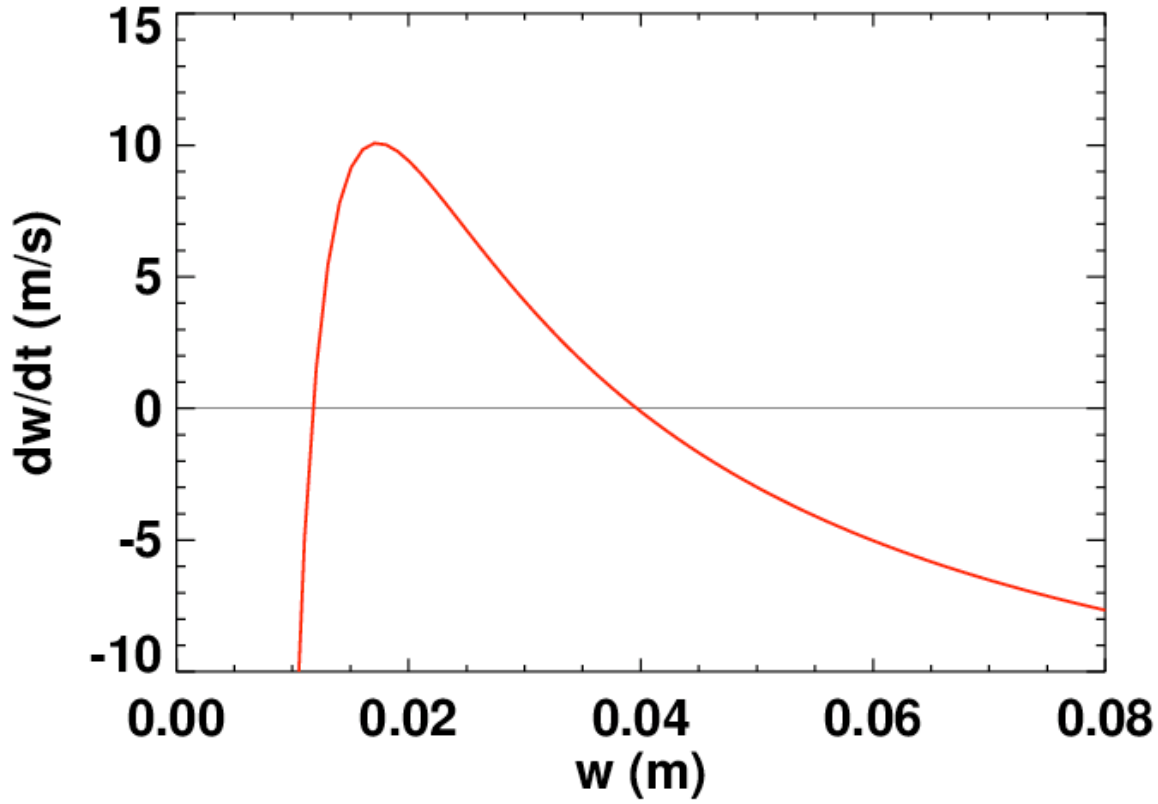
Skip to the XP form….stuff after this is not up to date.

Very Basic Background Information on the 3/2 NTM

“Standard” Model of the 3/2 NTM

MRE:

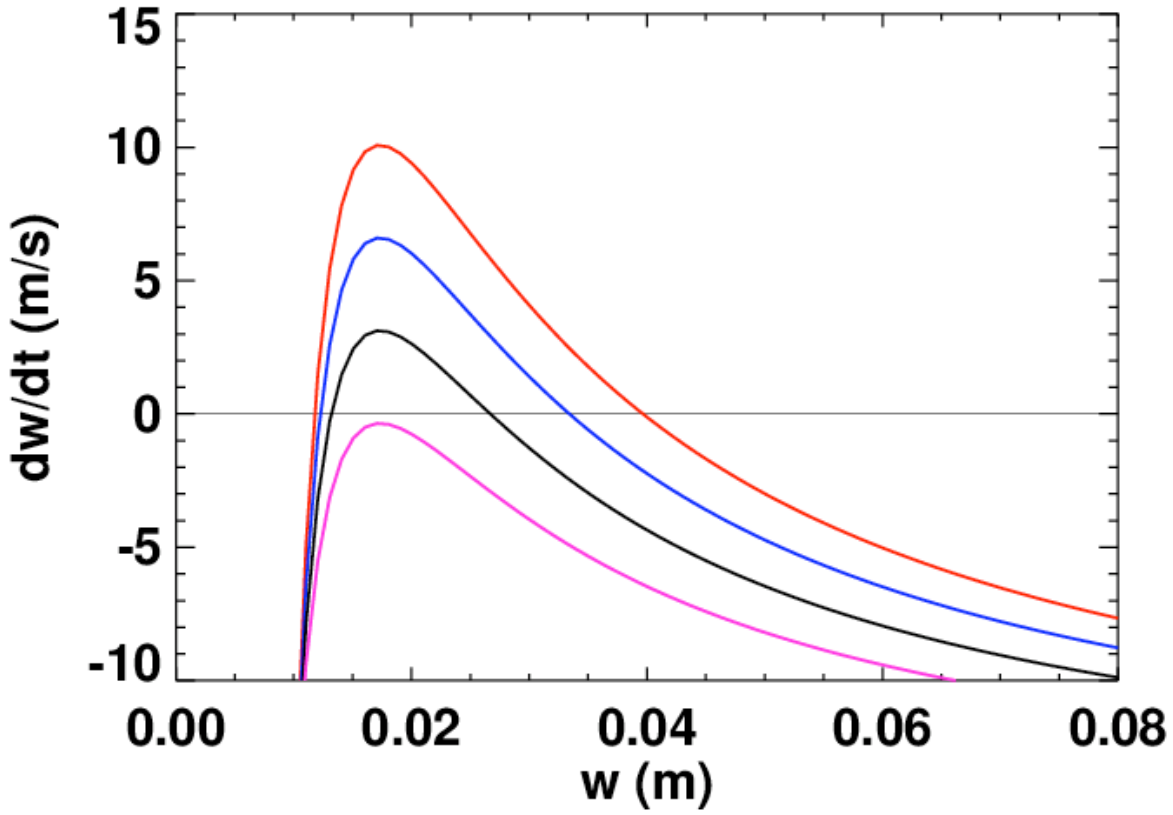
$$\frac{\tau_R}{r^2}\frac{dw}{dt} = \Delta' + a_{bs}\varepsilon^{1/2}\frac{L_q}{L_P}\frac{\beta_P}{w}\left(1-\frac{w_{pol}^2}{w^2}\right)$$



β_P=1.5
$r_s\Delta'$=-4
τ_R =0.05 sec.
L_q=0.5 m
L_P=-0.4 m
r_s=0.2 m
w_{pol}=0.01 m

Mode Can Restabilize as β_P is Reduced (I)

Restabilization of the mode as β_P is reduced.

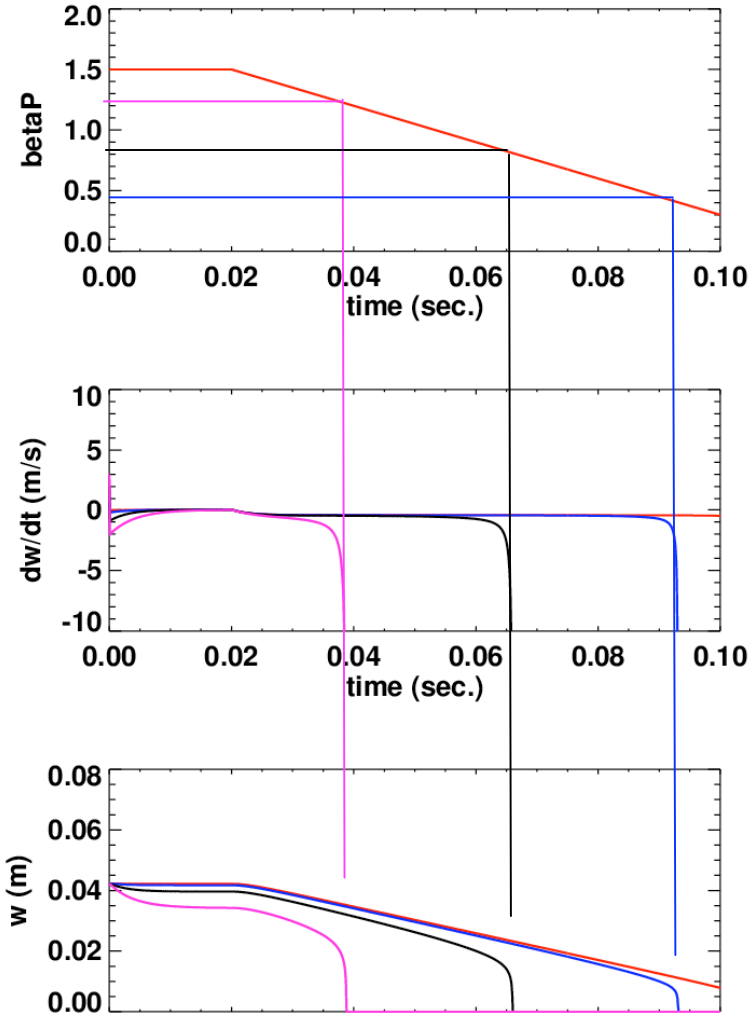


β_P=1.5
β_P =1.3
β_P =1.1
β_P =0.9

$r_s\Delta'$=-4
τ_R =0.05 sec.
L_q=0.5 m
L_P=-0.4 m
r_s=0.2 m
w_{pol}=0.01 m

Mode Can Restabilize as β_P is Reduced (II)

w_{pol}=1.5 cm
w_{pol}=1.0 cm
w_{pol}=0.5 cm
w_{pol}=0.25 cm



$r_s\Delta'$=-4
τ_R =0.05 sec.
L_q=0.5 m
L_P=-0.4 m
r_s=0.2 m

This β_P dependence is a defining feature of an NTM.

Step 2 of XP: Small Island Threshold (20 Shots)

This provides "proof" that neoclassical physics is involved…most important step.

- Assume that we can strike the mode…
- Attempt to decrease β_P using NBI ramp-down.
- For 2 Source recipe (A&B)
  - begin by modulating B 10 on / 10 off
  - If that doesn't work, modulate B 10 on / 20 off
  - If that doesn't work, Turn B off.
- Repeat for three values of I_P (will triggering work for all I_P ?)
- If possible, use n=1 feedback, n=3 correction, to avoid locking.

I_P (kA)	B_T	Voltage on Source B	Shots
900	4.5	80	5
700	3.5 (will we have MSE calibrations here?)	90	7
1100	5.5	70	7

- Do we need to scale P_{NBI} to adjust for confinement improvements at higher B_T, I_P?

Step 3 of XP 834: Test The Recipe

3.1: Test of Triggering (assuming n=2 configuration): Applied n=2 perturbation with D_2 glow (2-7 shots),

3.1a: Add 50 msec pulse of SPA n=2 currents (3kA, -1.5kA, -1.5kA).→w≈.007m

3.1b: If mode strikes, then goto 3.1d

3.1c: If mode doesn't strike, apply field for 100 msec, 150 msec, 200 msec, until plasma either locks and explodes, or mode strikes. If mode strikes:

3.1d: Reduce SPA currents in 15% increments until mode no longer strikes

Should we do a similar "jolt" with n=3 if in odd connections?

3.2: Test of H-mode Requirement: Early n>1 Perturbation for Beam Triggering

- Use most reliable beam timing and trigger method from above.
- Eliminate D_2 glow, add 40 msec blip of unused source at t=0.08→Early H-mode.

SPA 1 (odd)	SPA 2 (odd)	SPA 3 (odd)
0.0<t<0.24, 1.8 kA	0.0<t<0.24, 1.8 kA	Off During Ramp
0.0<t<0.24, 3.0 kA	0.0<t<0.24, 3.0 kA	Off During Ramp

Step 3 of XP: Impact of Rotation on Small Island Physics (5 shots)

…assumes that RWM coils are in the odd configuration…

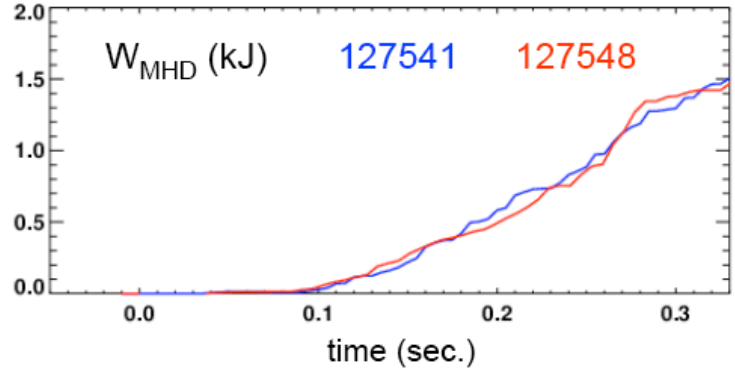
- Take best case from step 2.
- Use scan of n=3 braking amplitude during rampdown.
- Bring in the braking at t=0.3, ramping till t=0.35.
- Use three braking levels (anti-correcting) :
  - 300,600,900.
- Items to look for:
  - Saturated island width.
  - Different marginal β_P.

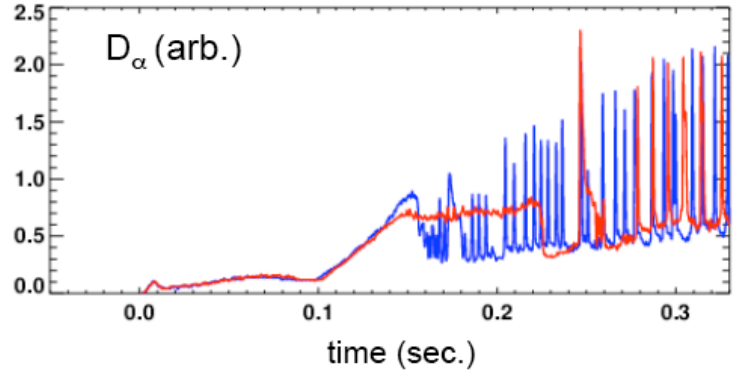
Additional:

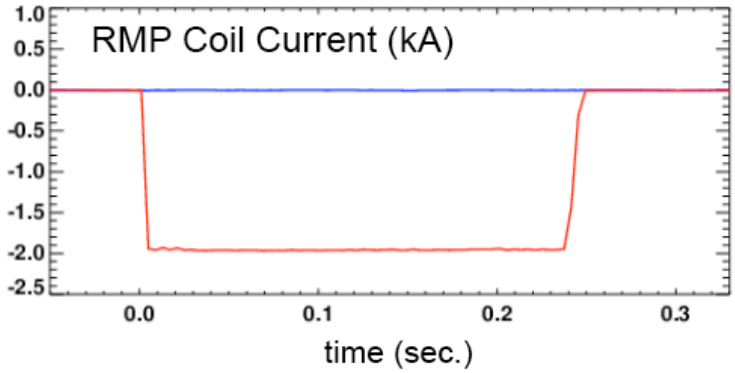
- Gas system configured for D_2 and He glow.
- If LITER recently used, start day with 15 minutes of D_2 glow, followed by He.
- Critical that the following diagnostics all work.
  - TS
  - CHERS
  - MSE
  - Poloidal and high-n Mirnov Arrays
  - USXR
- Assuming succesful execution, need PEST-III accurate modeling.

We *may* have another way to delay the H-mode

- Method inadvertently developed during ELM suppression XPs.
- Apply large n=2 field during current ramp.
- Unclear if larger EFC coil currents would have held off H-mode until current turned off.
- Opportunity to purposefully evaluate the method in the standard high-κ, high δ shape.
- Method did not work for 6MW input power fiducial, but these "recipe" shots have only 4MW.







Big Question: What is proper Configuration of RWM Coils?

- Arguments for Odd Connections:
  - We can use feedback to help during rampdown.
  - Can still “jolt” the plasma with n=3 fields.
  - Can use n=3 braking, which is NOT resonant with mode.
- Argument for Even Connections:
  - Can make a perturbation of correct n-number, for potential triggering.
  - Has supressed the H-mode (in at least one configuration)

I am inclining toward the Odd Connection.

We *may* have another way to generate the seed perturbation

- Use applied n=2 field to open a seed island.
- Used (for instance, with n=1) on Compass[1] to generate 2/1 islands.
  - Apply n=1 fields to generate locked island at low-β.
  - Turn off error fields, allowing island to both decay and spin up, while ramping-up β with ECH.
  - The island grows when β becomes large enough.
- Prescription for NSTX
  - *Rotating plasma and fixed perturbation is different than in Compass.*
  - …on the other hand, we can certainly make a notable perturbation
  - Establish baseline discharge with a "beam-trigger" mode, then turn off the beam perturbation (probably just A+B).
  - At fixed β_P, vary the size of the seed island: (3kA, -1.5kA, -1.5kA).→w=.007m
  - If coils are in odd-configuration, we can try "jolting" it with n=3…

$$EFC = \left[2I_{RWM}, -I_{RWM}, -I_{RWM}, 2I_{RWM}, -I_{RWM}, -I_{RWM}\right]$$
$$I_{RWM} = 1 \Rightarrow B_{R,3,2} \approx .0002\ Gauss$$

$$q = 1.5,\ \frac{dq}{dr} \approx 9\ \textbf{(1/m)},\ \mathbf{B}_\theta \approx .08\ (T),$$
$$w = \mathbf{4}\sqrt{\frac{\mathbf{B_R} rq}{mq' B_\theta}} = 1.4\sqrt{B_R} = .00019\sqrt{I_{RWM}}$$

1: R. Buttery, et al, Nuclear Fusion

Mode Has NTM-like Beta Dependence (II)

Mode restabilizes as β_P is reduced

Some weak frequency evolution

β_P ramps down

Big Step from 6→2MW
(ion power balance experiment)