

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

Exploratory XP

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Goals of the XP

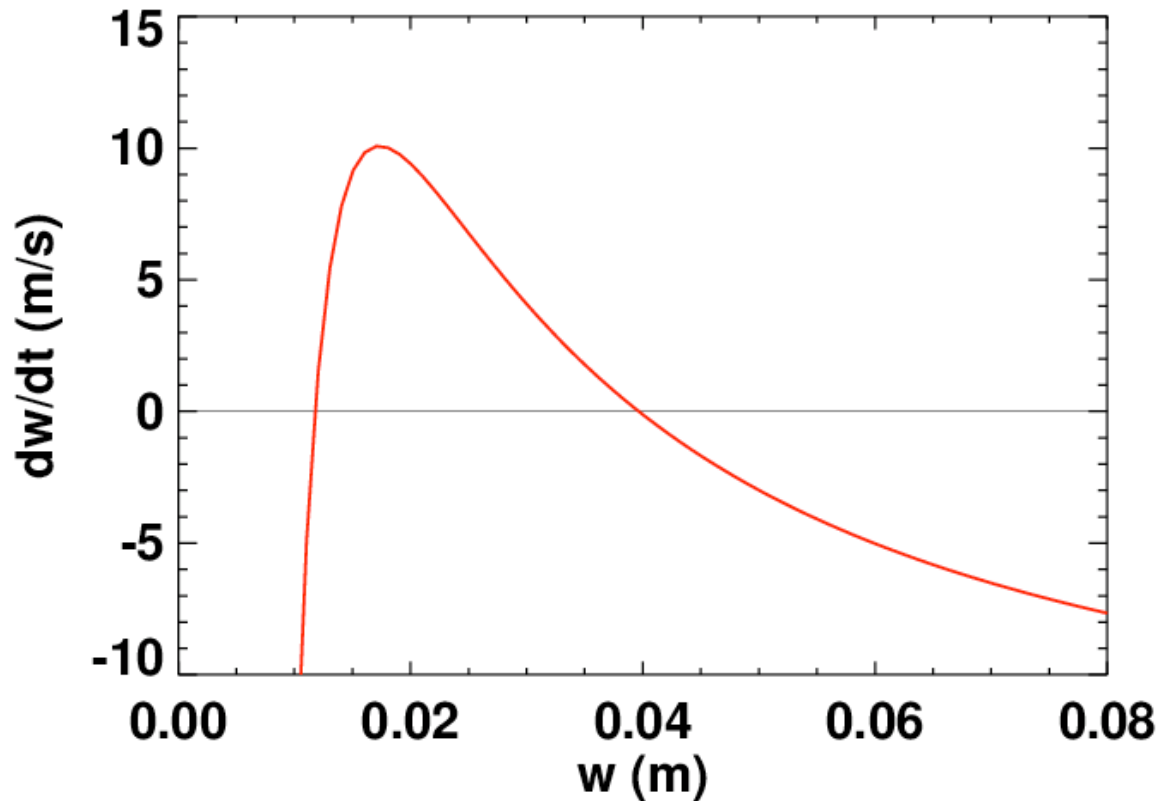
- Study methods of generating of 3/2 NTM in NSTX.
 - Delaying H-mode using either D_2 glow or early error fields.
 - Role of beam “trigger” to strike mode.
 - Using external $n=2$ fields to open an island
- Use NBI ramp-down to decrease beta and restabilize the mode.
 - Information on the small island physics available during rampdown.
 - Reliable mode generation necessary for preprogrammed rampdown.
- Use most reliable “striking” method to study dependence on rotation with $n=2$ braking.

Very Basic Background Information on the 3/2 NTM

“Standard” Model of the 3/2 NTM

MRE:

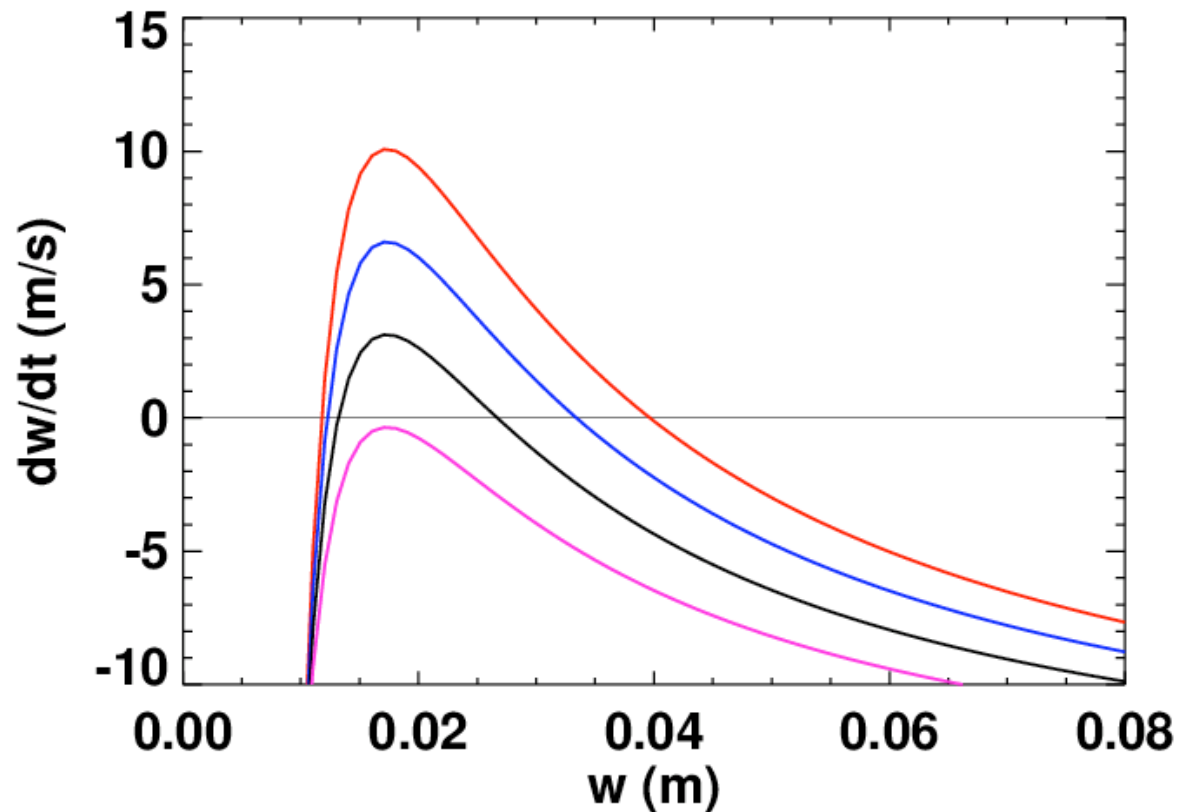
$$\frac{\tau_R}{r^2} \frac{dw}{dt} = \Delta' + a_{bs} \epsilon^{1/2} \frac{L_q}{L_p} \frac{\beta_P}{w} \left(1 - \frac{w_{pol}^2}{w^2} \right)$$



$$\begin{aligned} \beta_P &= 1.5 \\ r_s \Delta' &= -4 \\ \tau_R &= 0.05 \text{ sec.} \\ L_q &= 0.5 \text{ m} \\ L_p &= -0.4 \text{ m} \\ r_s &= 0.2 \text{ m} \\ w_{pol} &= 0.01 \text{ m} \end{aligned}$$

Mode Can Restabilize as β_P is Reduced (I)

Restabilization of the mode as β_P is reduced.



$$\beta_P = 1.5$$

$$\beta_P = 1.3$$

$$\beta_P = 1.1$$

$$\beta_P = 0.9$$

$$r_s \Delta' = -4$$

$$\tau_R = 0.05 \text{ sec.}$$

$$L_q = 0.5 \text{ m}$$

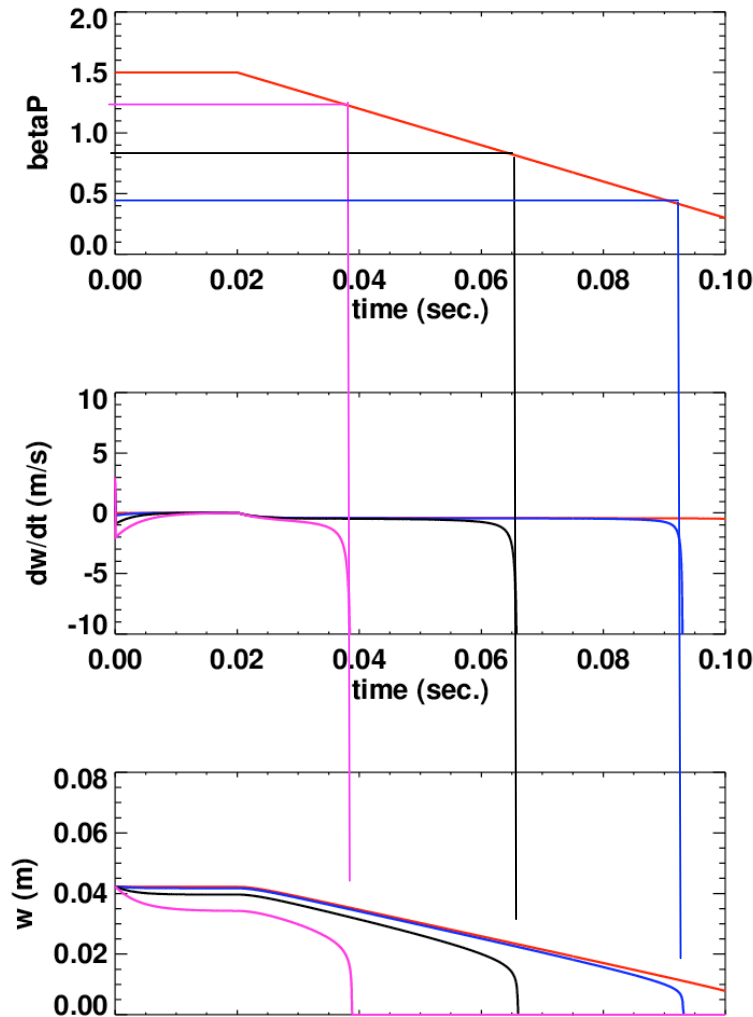
$$L_P = -0.4 \text{ m}$$

$$r_s = 0.2 \text{ m}$$

$$W_{pol} = 0.01 \text{ m}$$

Mode Can Restabilize as β_P is Reduced (II)

$w_{pol} = 1.5 \text{ cm}$
 $w_{pol} = 1.0 \text{ cm}$
 $w_{pol} = 0.5 \text{ cm}$
 $w_{pol} = 0.25 \text{ cm}$

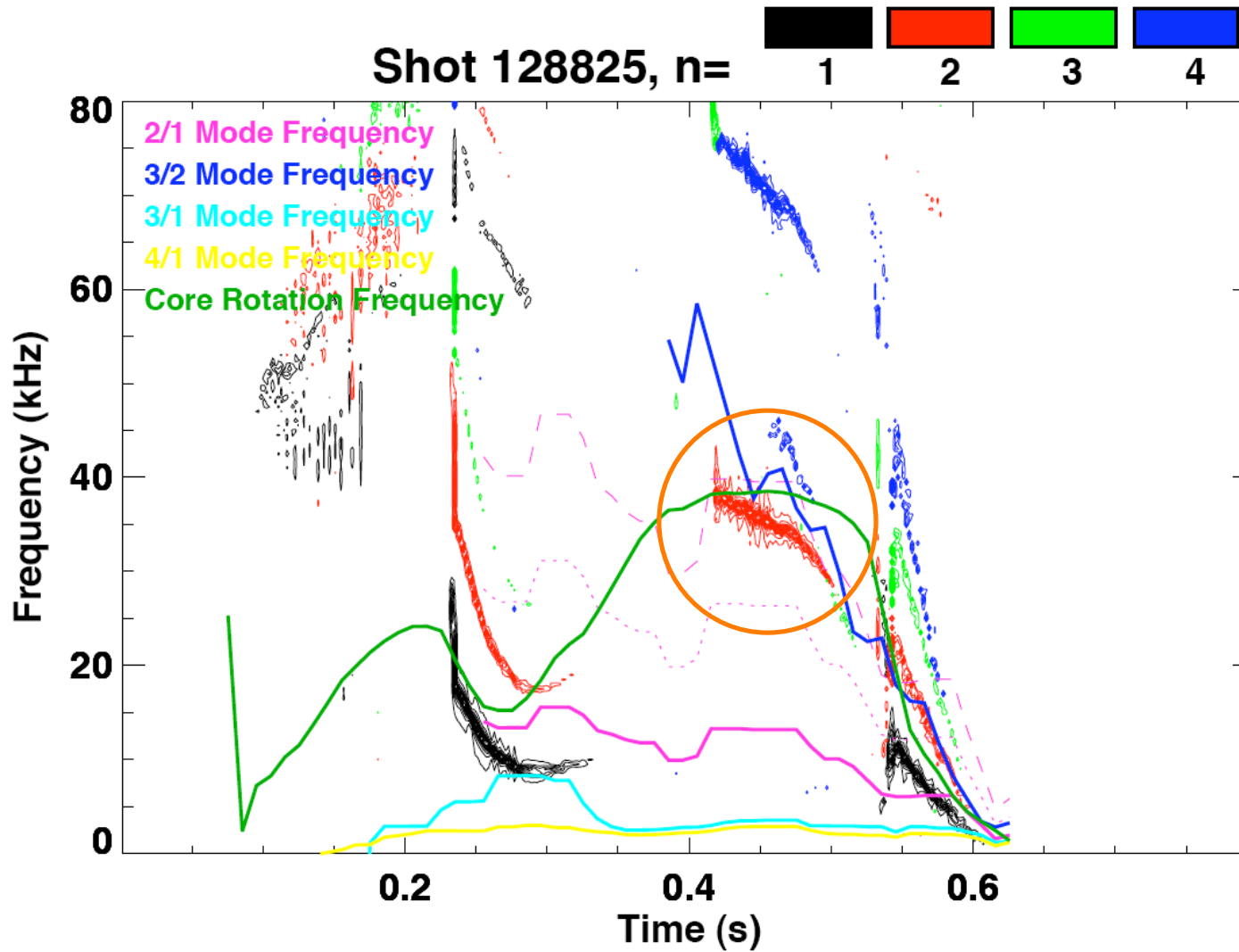


$r_s \Delta' = -4$
 $\tau_R = 0.05 \text{ sec.}$
 $L_q = 0.5 \text{ m}$
 $L_P = -0.4 \text{ m}$
 $r_s = 0.2 \text{ m}$

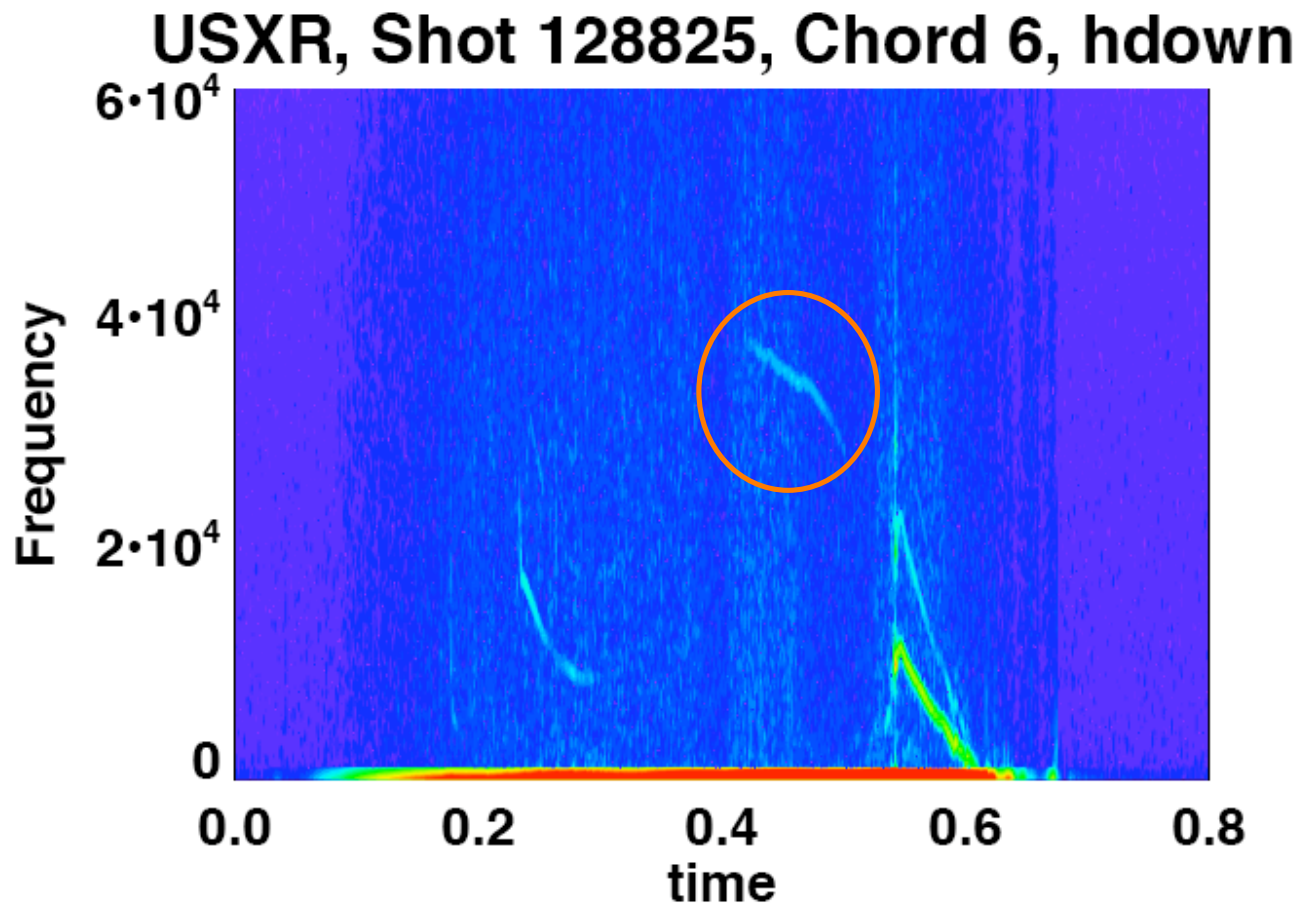
This β_P dependence is a defining feature of an NTM.

Observations of 3/2 NTM in NSTX

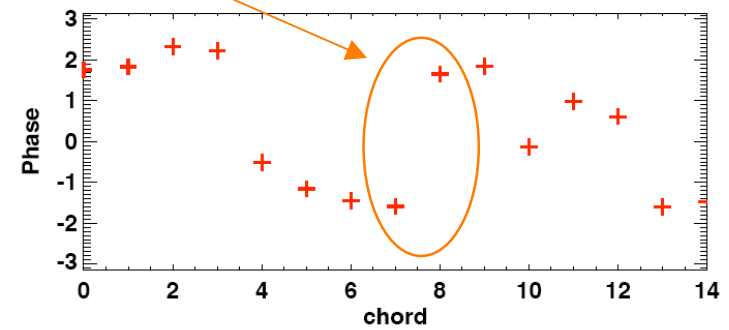
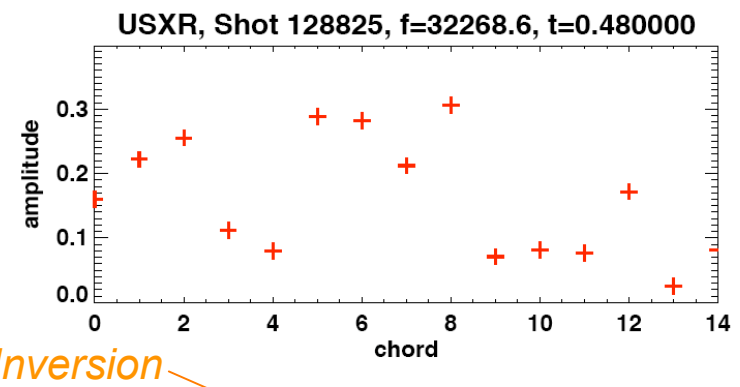
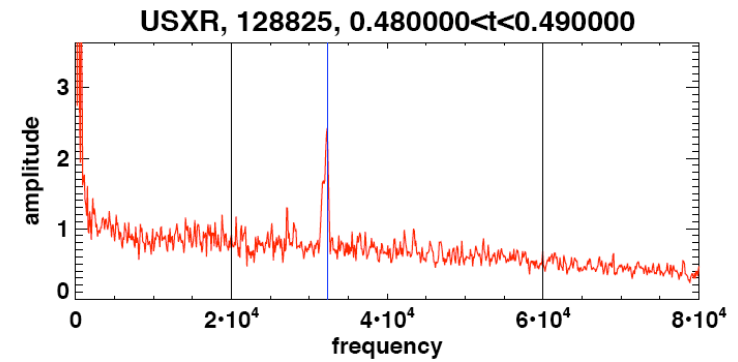
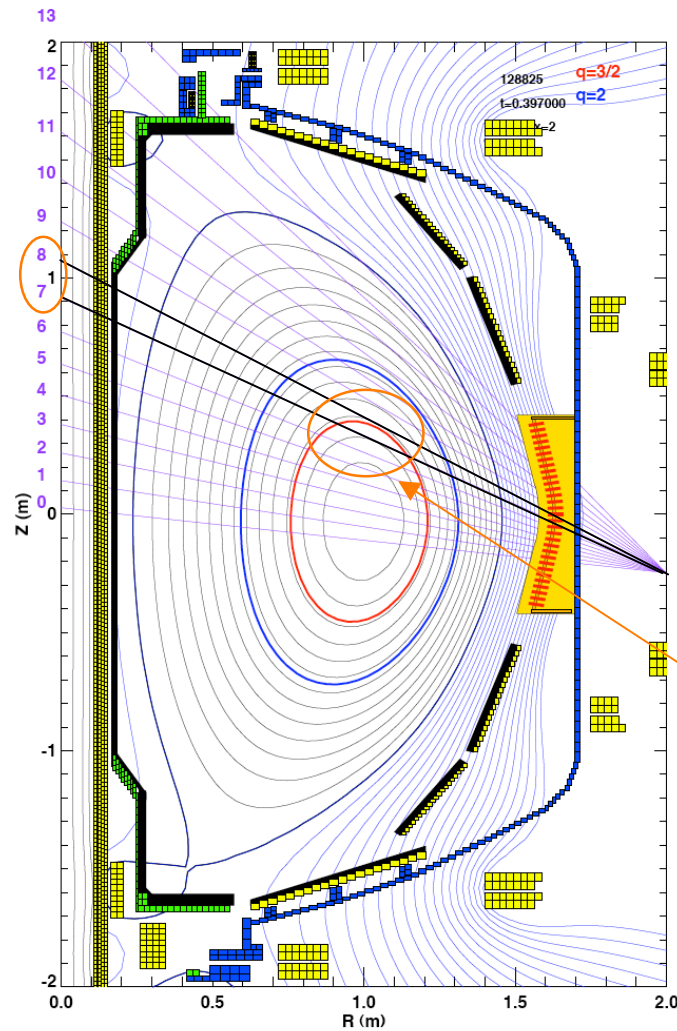
We have a Recipe For Generating 3/2 modes



Mode Weekly Visible With the USXR System

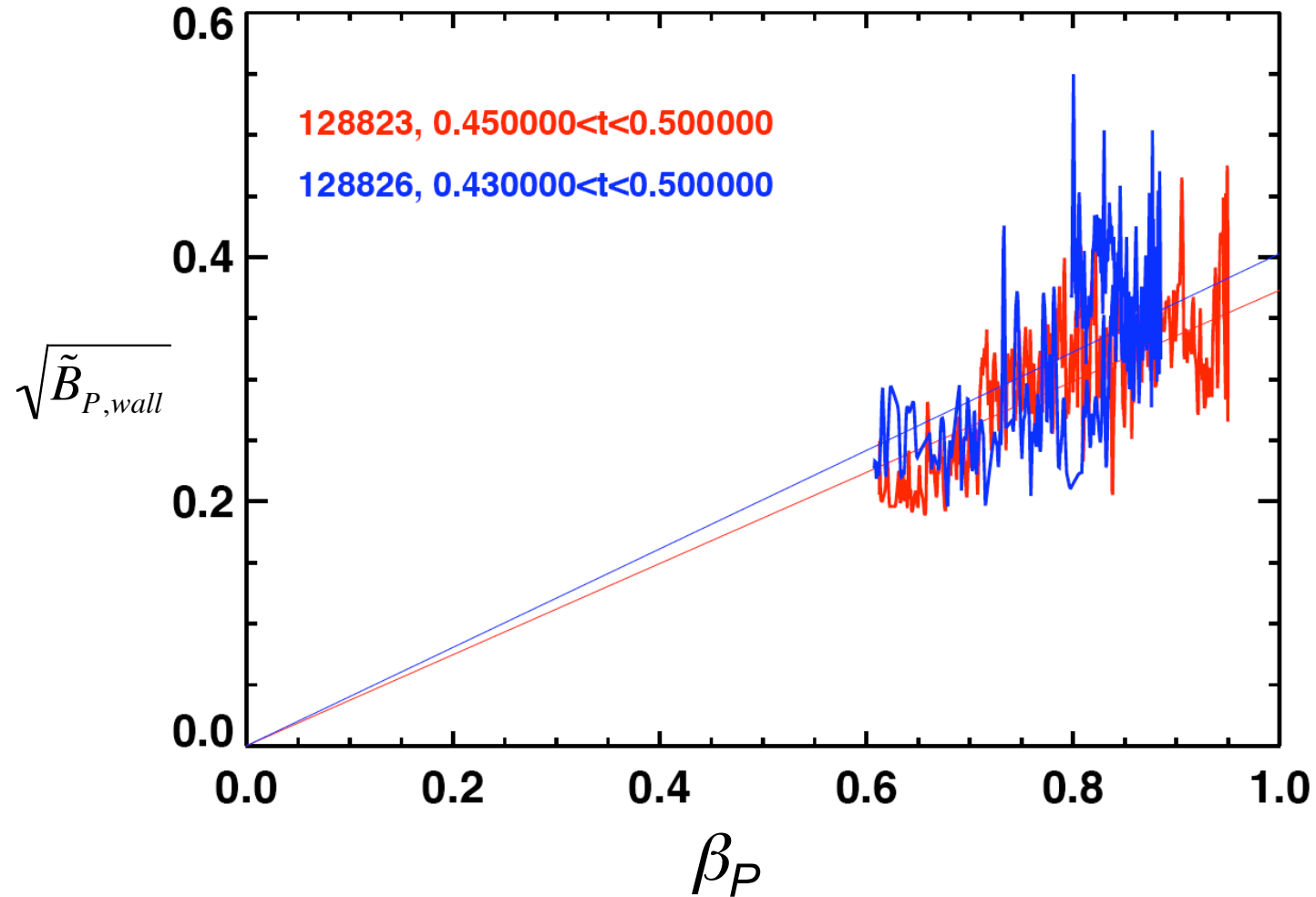


USXR Inversion Radius at 3/2 Surface



Phase Inversion

Mode Has NTM-like Beta Dependence (I)



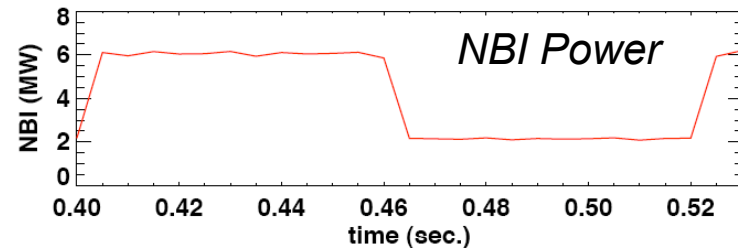
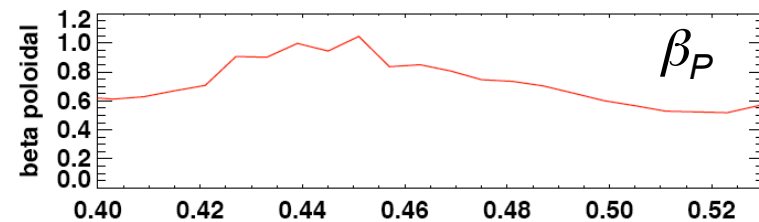
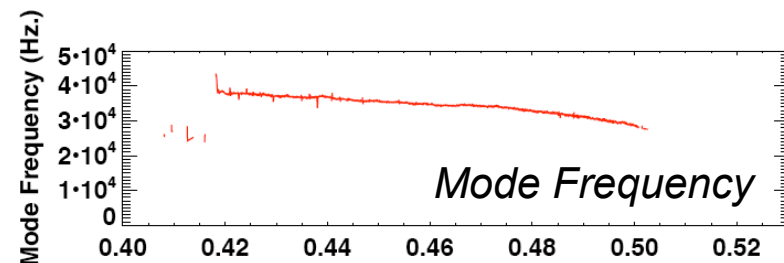
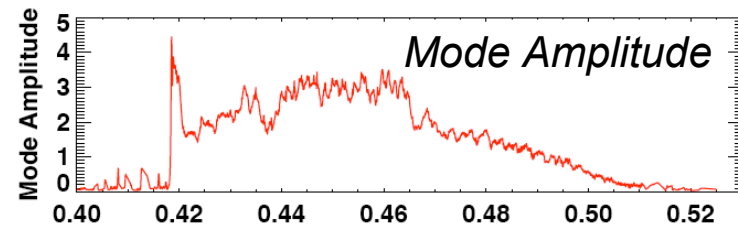
Mode Has NTM-like Beta Dependence (II)

Mode restabilizes as β_p is reduced

Some weak frequency evolution

β_p ramps down

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



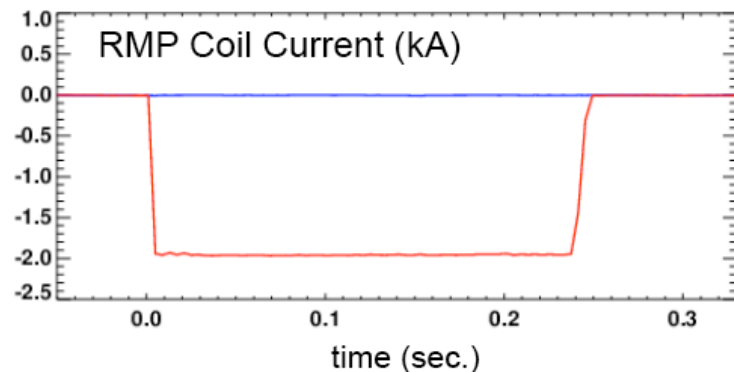
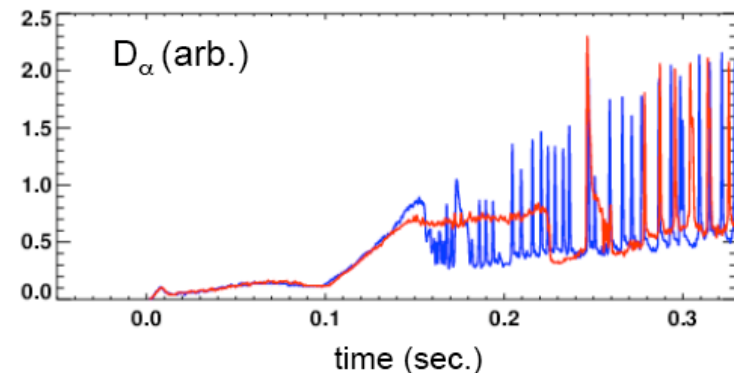
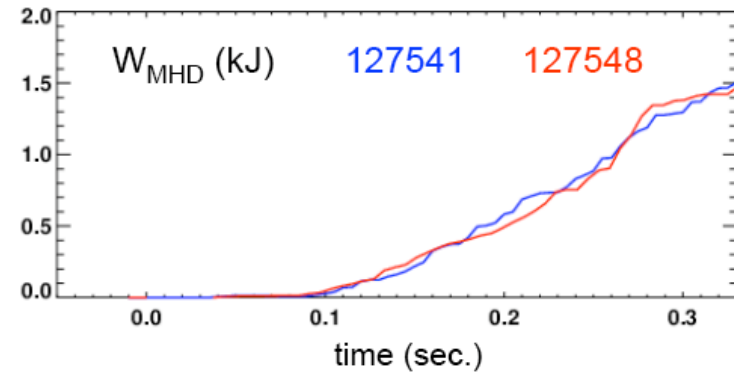
What is the recipe, and which part matters?

- Recipe (found in a beam modulated Ion Power Balance Experiment):
 - 15 minute shot cycle, 1 minute D₂ 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.
- What is the important ingredient?
 - Does the delayed H-mode simply allow faster current penetration, or does D₂ glow change something else?
 - Is there another way to generate the seed island in these non-sawteething plasmas?

Physics Elements of the XP (Essentially Random Order)

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.



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 Compass¹ 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). $\rightarrow w = .007\text{m}$
 - If coils are in odd-configuration, we can try “jolting” it with n=3...

$$EFC = [2I_{RWM}, -I_{RWM}, -I_{RWM}, 2I_{RWM}, -I_{RWM}, -I_{RWM}]$$

$$I_{RWM} = 1 \Rightarrow B_{R,3,2} \approx .0002 \text{ Gauss}$$

$$q = 1.5, \frac{dq}{dr} \approx 9 \text{ (1/m)}, \mathbf{B}_\theta \approx .08 \text{ (T)},$$

$$w = 4 \sqrt{\frac{\mathbf{B}_R r q}{m q' B_\theta}} = 1.4 \sqrt{B_R} = .00019 \sqrt{I_{RWM}}$$

1: R. Buttery, et al, Nuclear Fusion

Need a Measure of the Island Width

Flat-spot not usually seen on TS 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.

USXR:

- Would like a 10 μ m and 100 μ m filter to start with.
- Rely on inversion techniques and island models

*Both tools need development, but show promise
J. Manickam has show some interest in helping here.*

Want to Study Restabilization

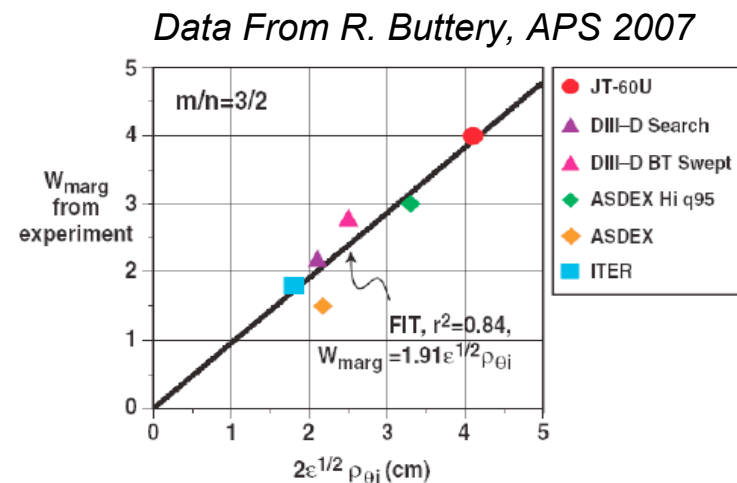
Most important part of XP.

- 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:

$$w_{\text{marg}} \sim \rho_{\theta,i} = \frac{2 \times 10^{-4} \sqrt{T_i(eV)}}{r_s B_\theta}$$

$$w_{\text{marg}} \sim \rho_{\theta,i} = \frac{2 \times 10^{-4} \sqrt{(T_i = 600)}}{(B_\theta = 0.15)} = 3 \text{ cm}$$

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



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 suppressed the H-mode (in at least one configuration)

I am inclining toward the Odd Connection.

Detailed Plan of the XP

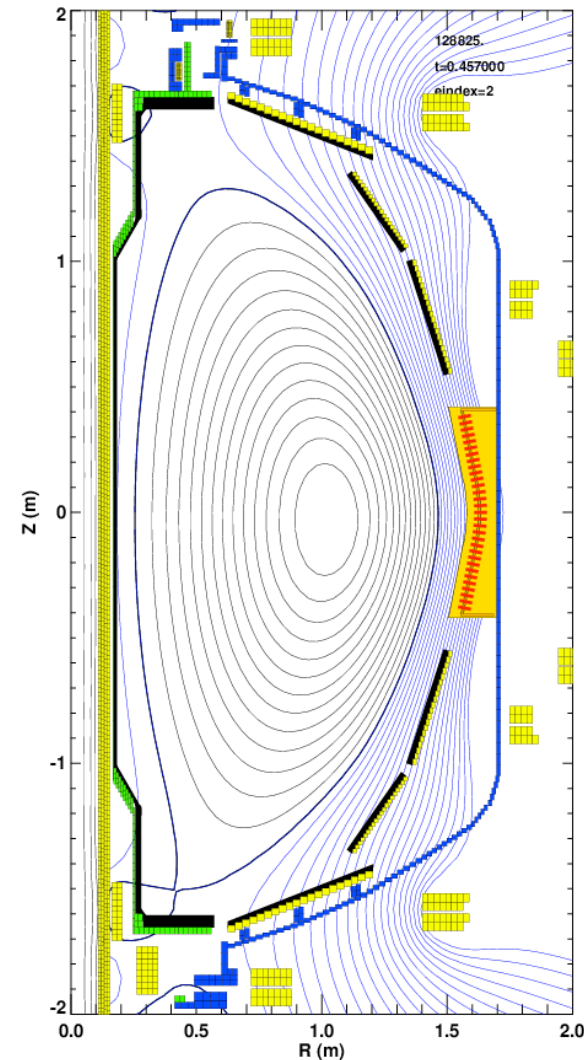
Step 1: Establish Reference Configuration With Mode (5 shots)

- Shot 128825, PF1A shot
- $I_p=900\text{kA}$
- $\kappa=2.25$
- $dr_{\text{sep}}=-0.7\text{ cm}$
- $\delta_l=0.75$, $\delta_u=0.45$
- Outer Gap: 10cm
- $I_{\text{TF}}=-53\text{ kA}$
- 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 $t=0.08$
 - @ $t=0.38$, turn off Source B
 - @ $t=0.39$, turn on B & C,
 - @ $t=0.4$, turn off C

If mode doesn't strike:

- make 10msec durations into 20 msec.
- Leave C on.
- Dropping κ .



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). $\rightarrow w \approx .007m$
 - 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 $t=0.08 \rightarrow$ 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 D₂ and He glow.
- If LITER recently used, start day with 15 minutes of D₂ glow, followed by He.
- Critical that the following diagnostics all work.
 - TS
 - CHERS
 - MSE
 - Poloidal and high-n Mirnov Arrays
 - USXR
- Assuming successful execution, need PEST-III accurate modeling.