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

Exploratory XP

S.P. Gerhardt, D. Gates

Goals of the XP

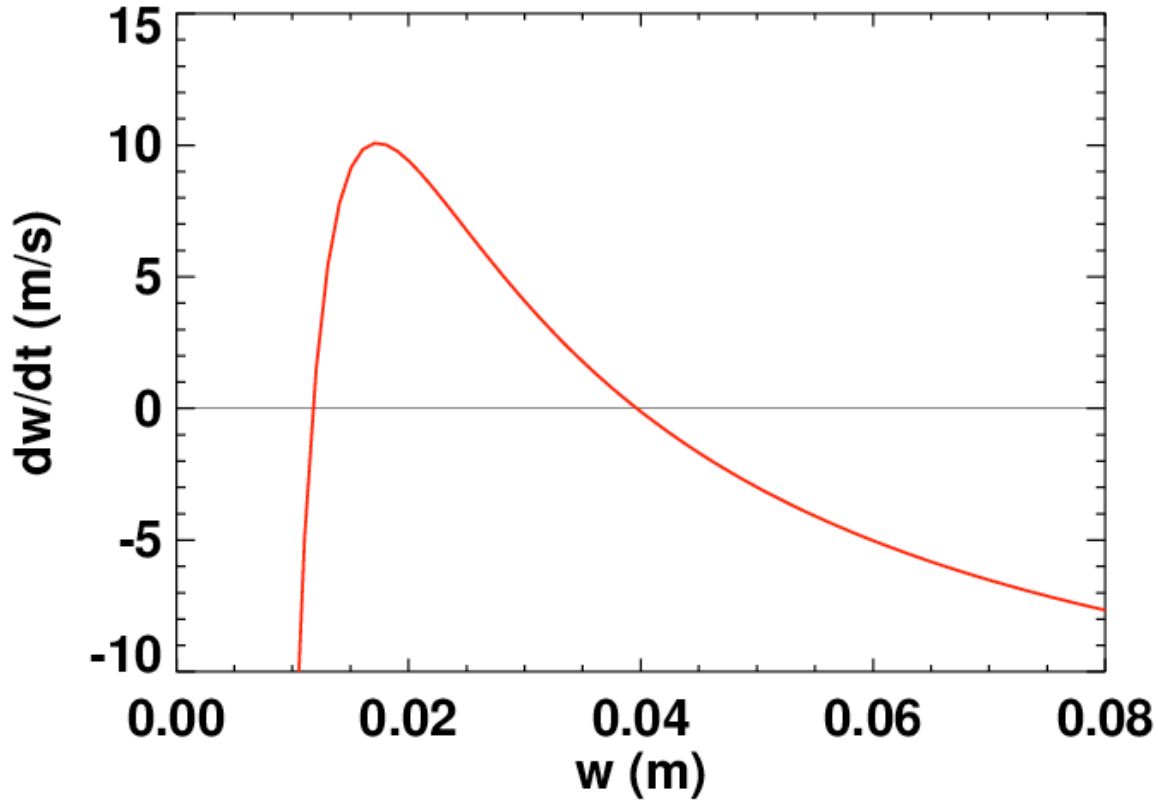
- Study methods of generating of 3/2 NTM in NSTX.
  - Delaying H-mode using either D_2 glow or early error fields.
  - Role of beam "trigger" to strike mode.
  - Using external n=2 fields to open an island
- Use NBI ramp-down to decrease beta and restabilize the mode.
  - Information on the small island 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:

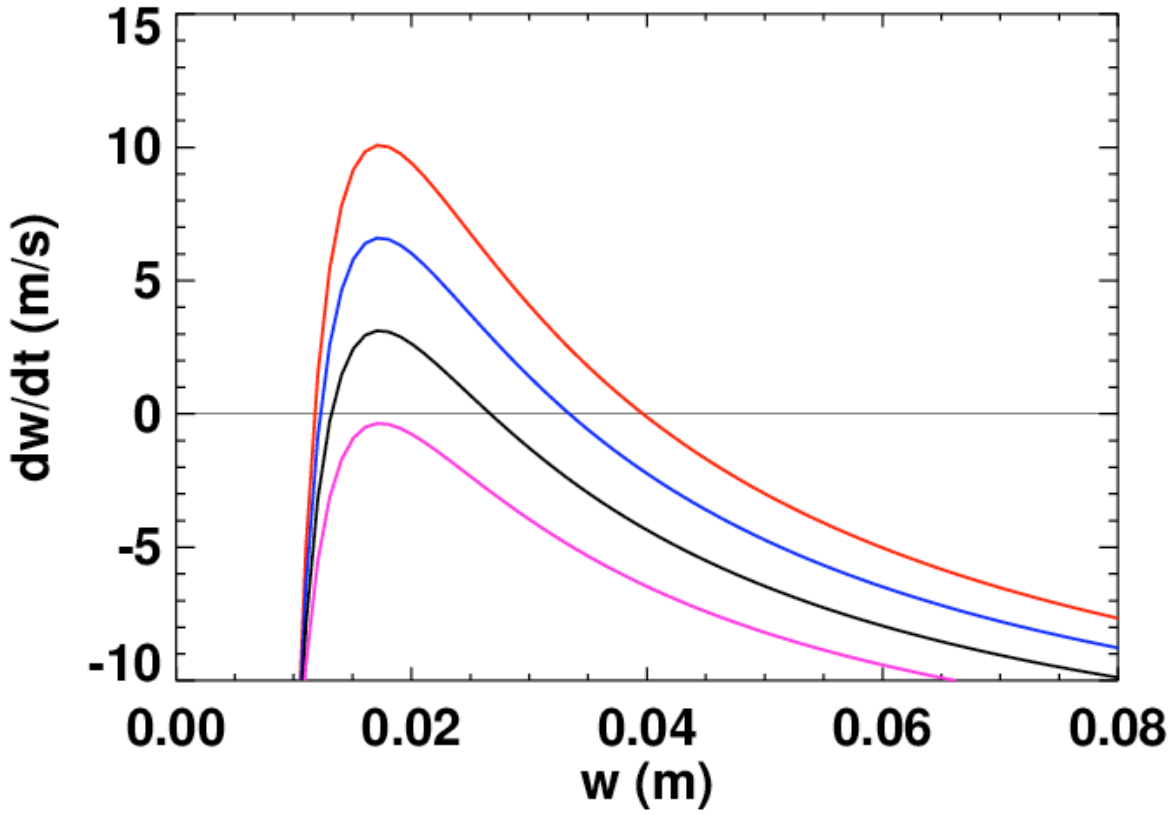
$$\frac{\tau_R}{r^2}\frac{dw}{dt} = \Delta' + a_{bs}\varepsilon^{1/2}\frac{L_q}{L_P}\frac{\beta_P}{w}\left(1-\frac{w_{pol}^2}{w^2}\right)$$



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.

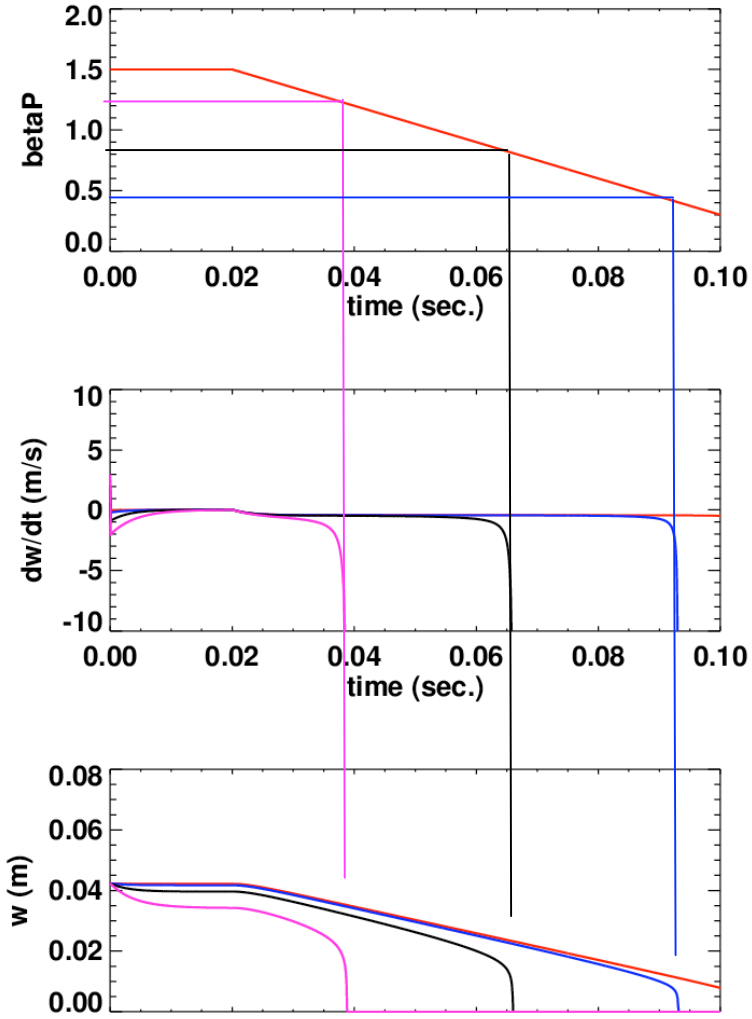


β_P=1.5
β_P =1.3
β_P =1.1
β_P =0.9

$r_s\Delta'$=-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

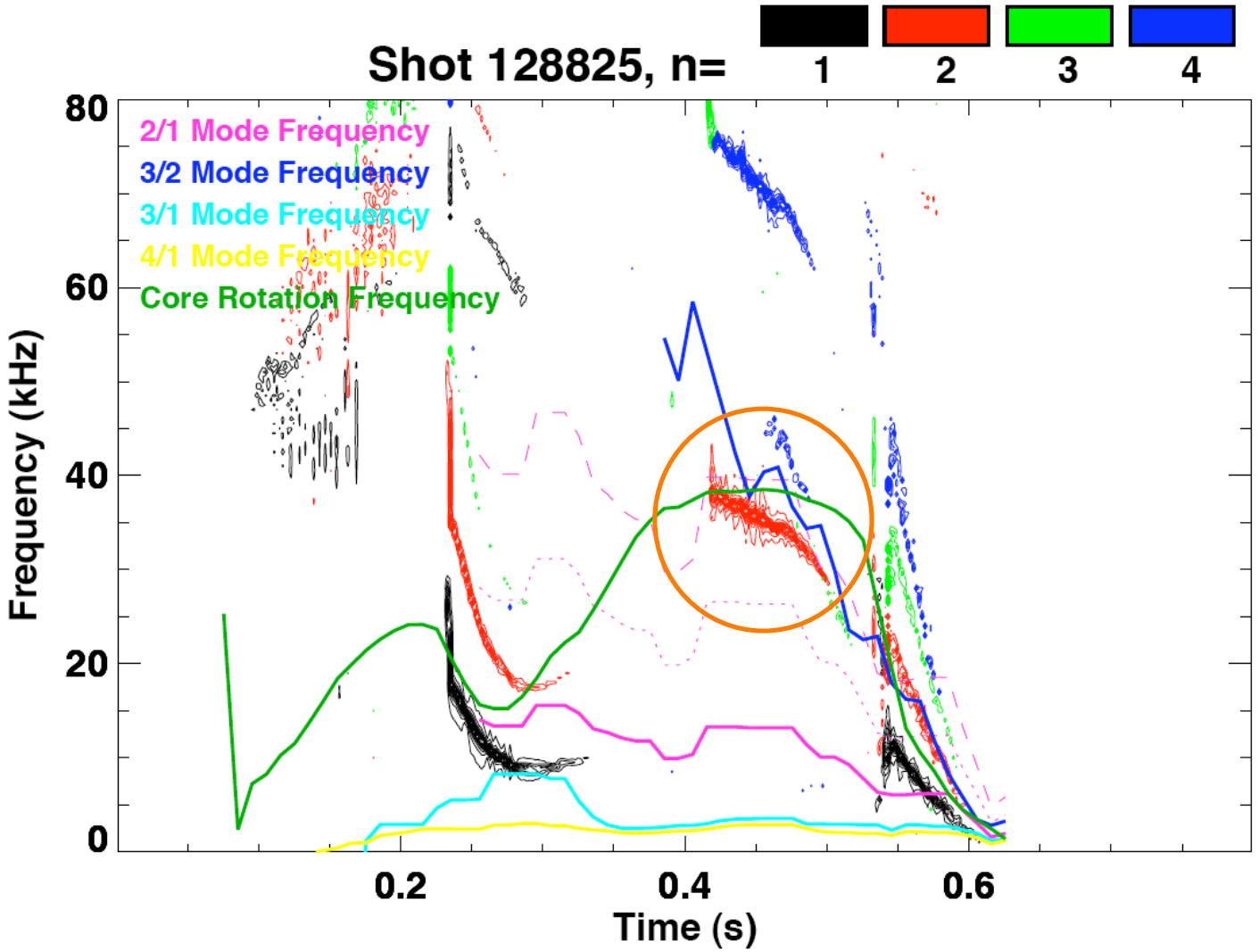


$r_s\Delta'$=-4
τ_R =0.05 sec.
L_q=0.5 m
L_P=-0.4 m
r_s=0.2 m

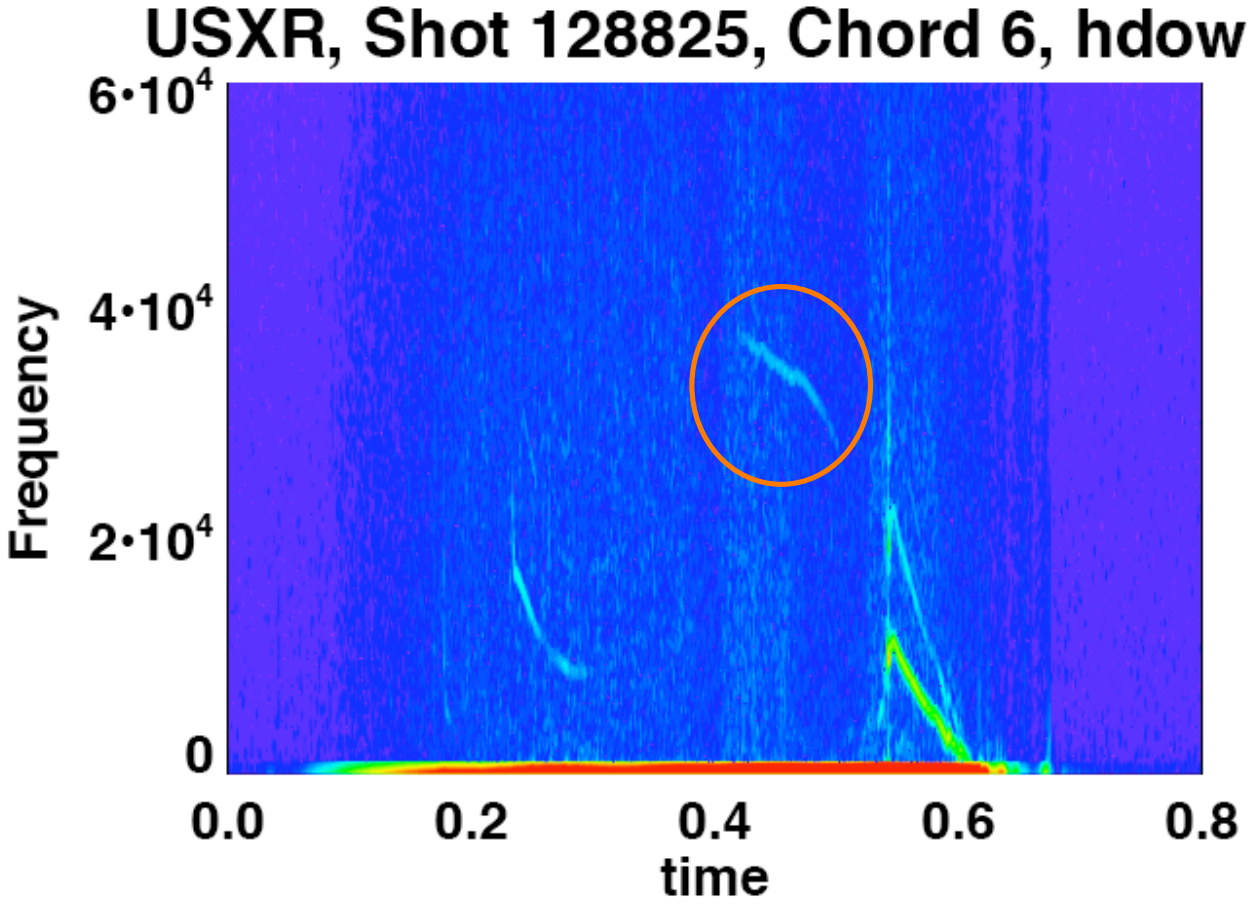
This β_P dependence is a defining feature of an NTM.

Observations of 3/2 NTM in NSTX

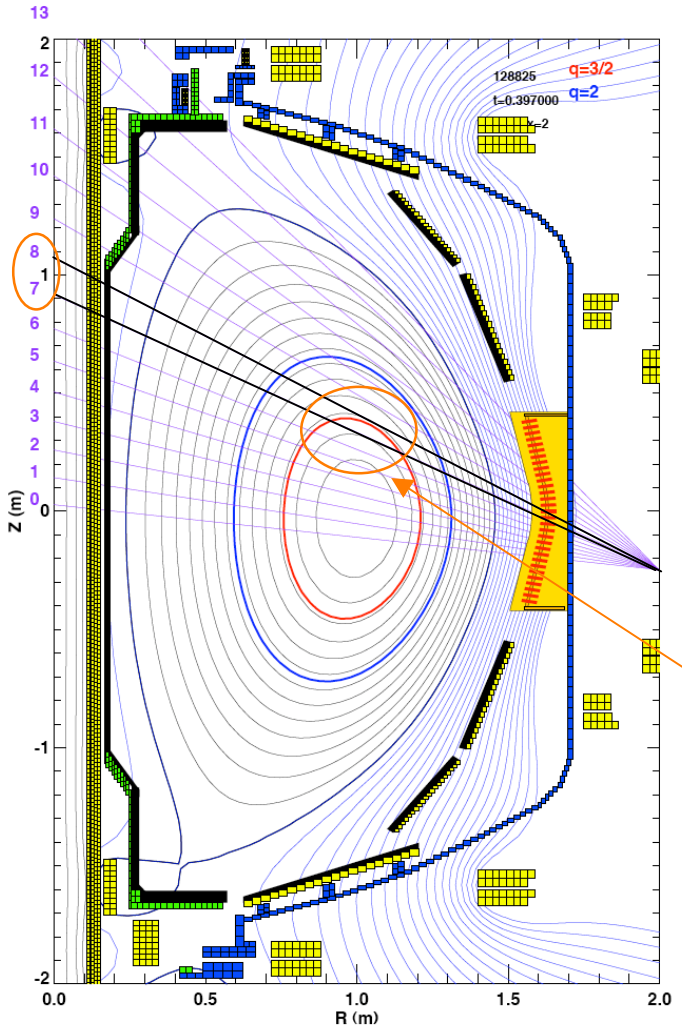
We have a Recipe For Generating 3/2 modes

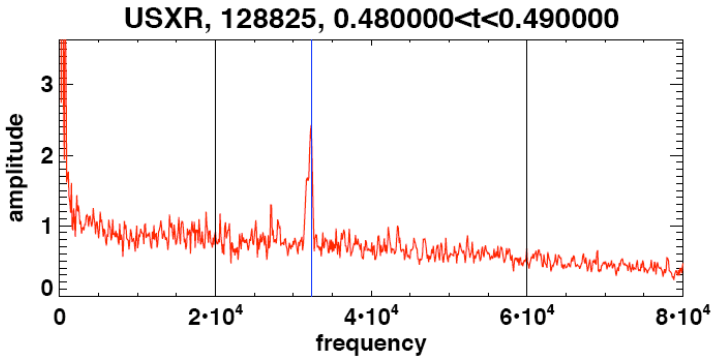


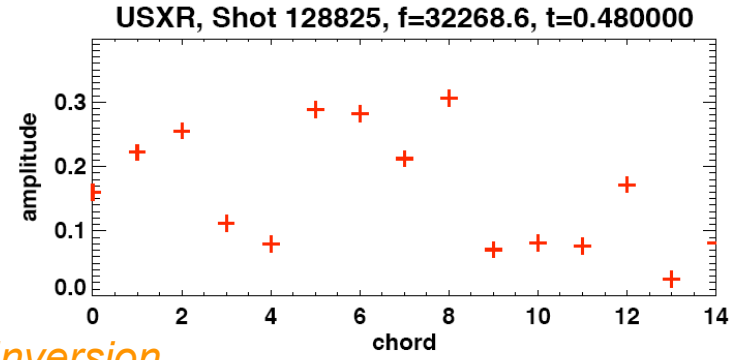
Mode Weekly Visible With the USXR System



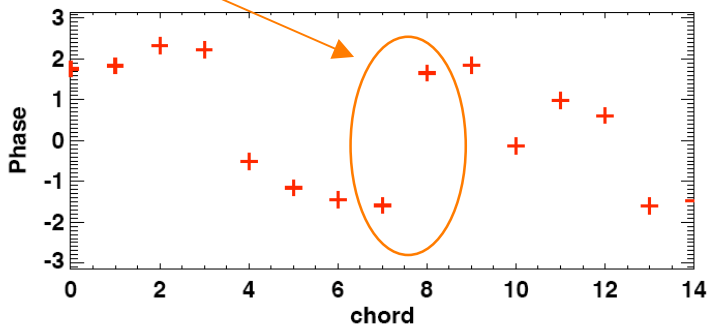
USXR Inversion Radius at 3/2 Surface



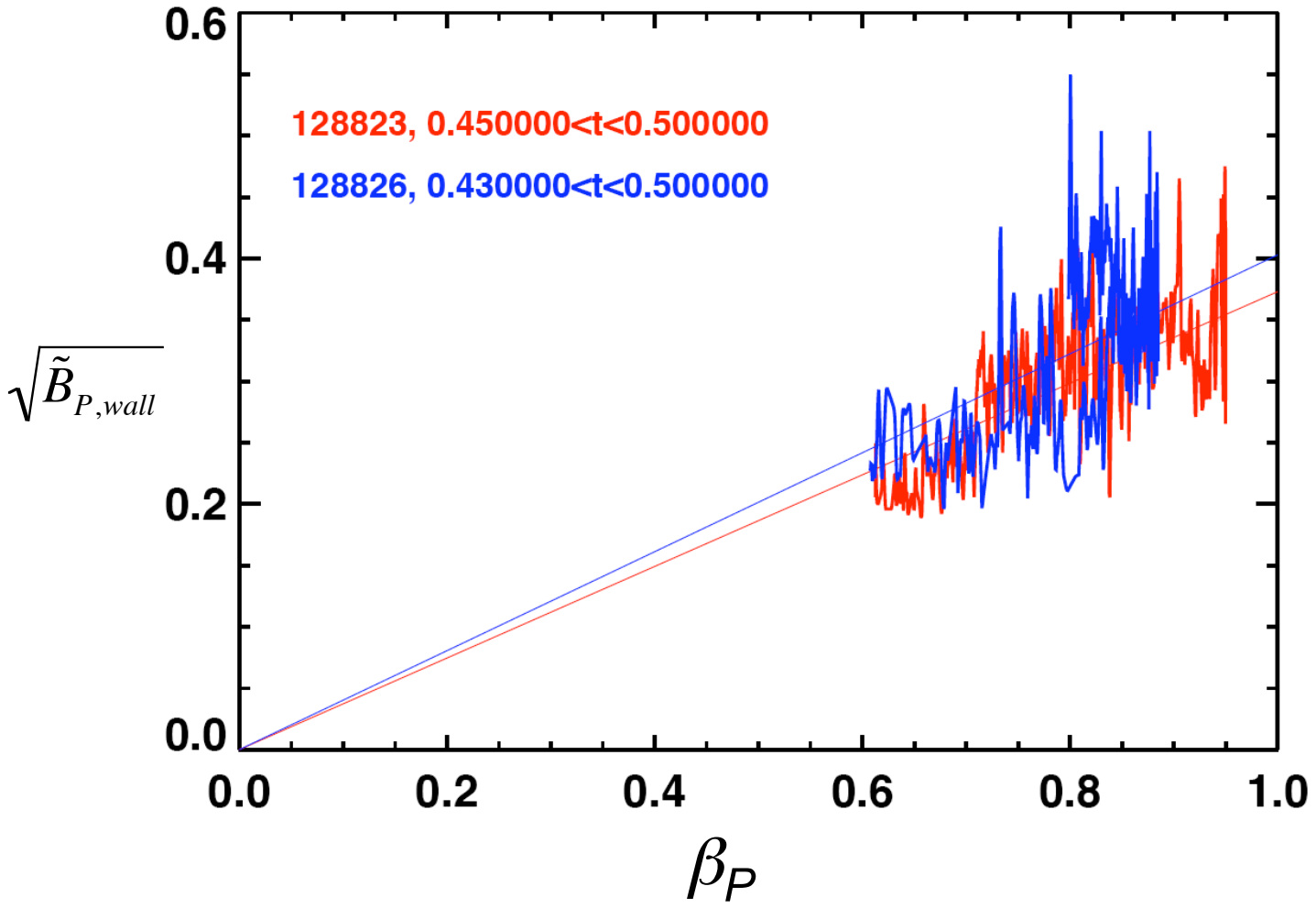




Phase Inversion



Mode Has NTM-like Beta Dependence (I)



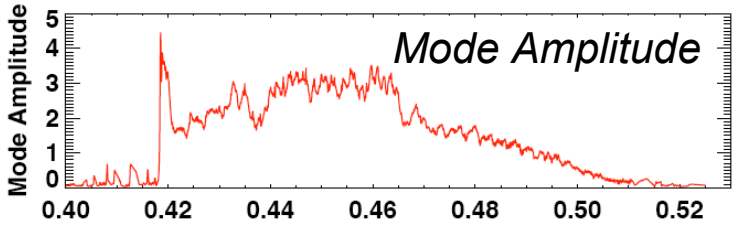
Mode Has NTM-like Beta Dependence (II)

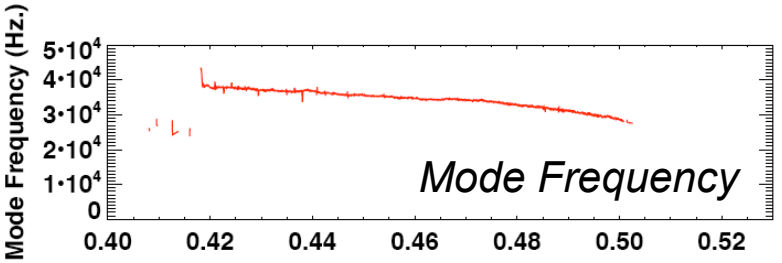
Mode restabilizes as β_P is reduced

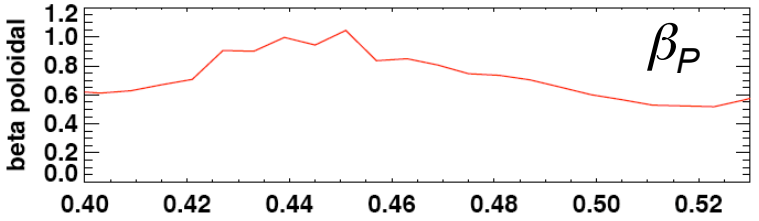
Some weak frequency evolution

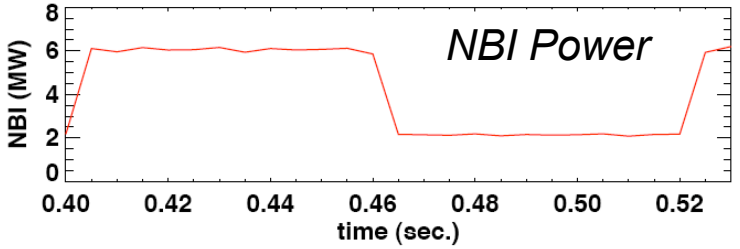
β_P ramps down

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









What is the recipe, and which part matters?

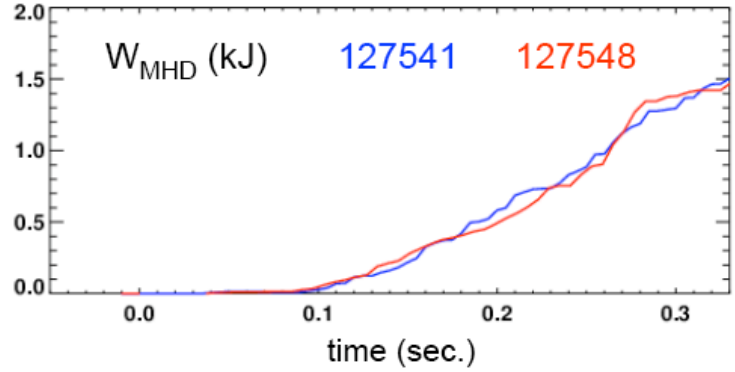
- Recipe (found in a beam modulated Ion Power Balance Experiment):
  - 15 minute shot cycle, 1 minute D_2 glow, followed by 8 minutes He glow.
    - Delays the H-mode to ~230 msec (i.e. end of the current ramp).
  - Step a beam source on (or 1 off, followed by 2 on).
    - Apparently generates a seed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

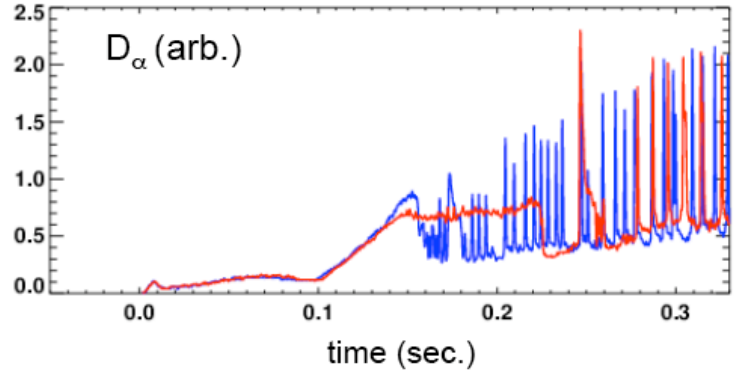
- What is the important ingredient?
  - Does the delayed H-mode simply allow faster current penetration, or does D_2 glow change something else?
  - Is there another way to generate the seed island in these non-sawteething plasmas?

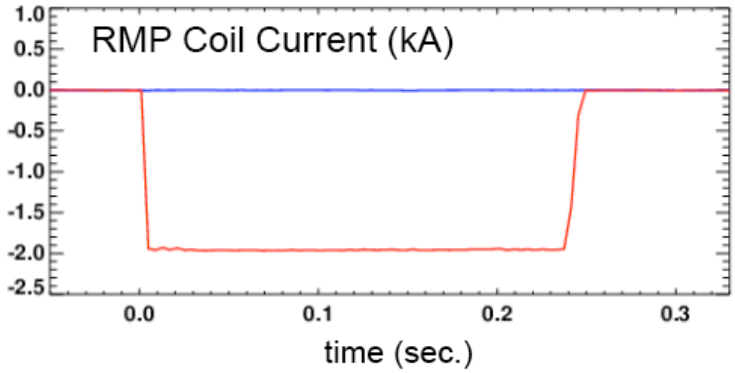
Physics Elements of the XP (Essentially Random Order)

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 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

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 10μm and 100μm 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.

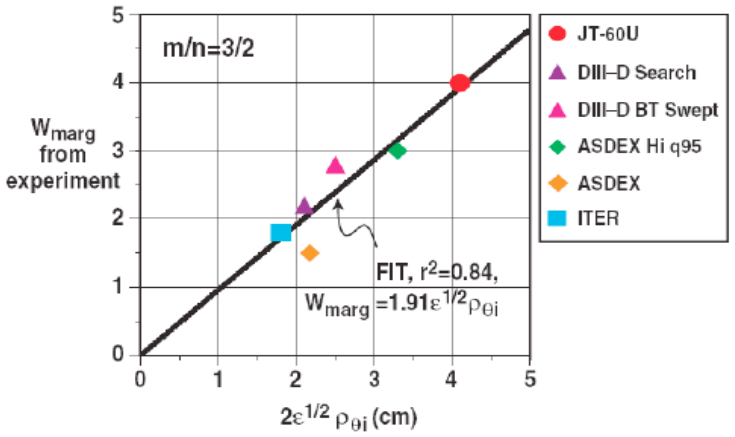
- Step NBI power down after mode strikes, in order to restabilize the mode and measure the marginal island width.
- Potential problems:
  - Loose H-mode before restabilization.
  - Plasma slows and locks.
  - m/n=2/1 mode strikes (will be included in 2/1 mode database ☺).
  - From P.W. Ross day, rapid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

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

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

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

Data From R. Buttery, APS 2007



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.

Detailed Plan of the XP

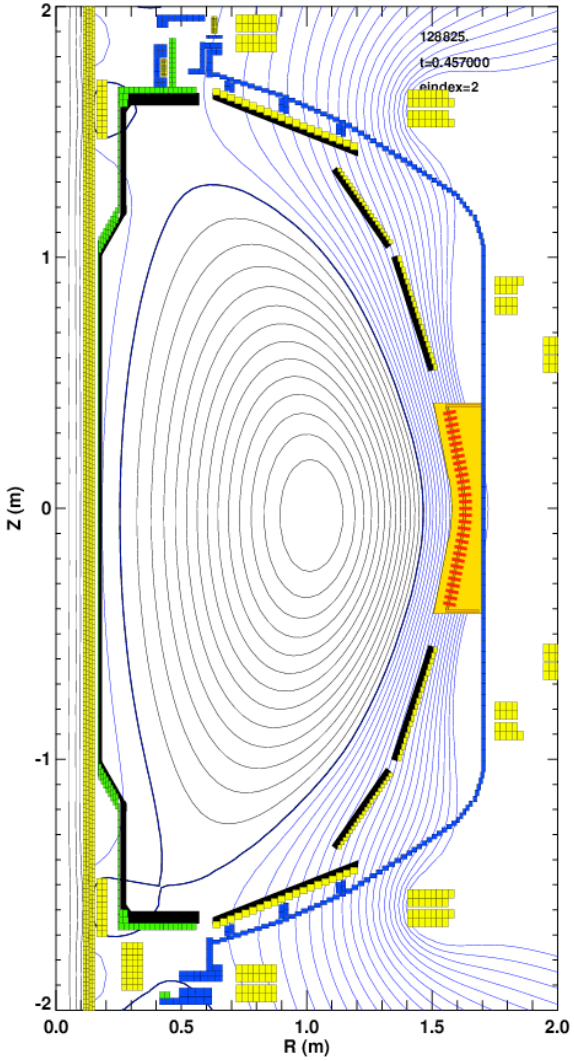
Step 1: Establish Reference Configuration With Mode (5 shots)

- 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=0.38, 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).→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.