XP932: Influence of Hot Ions on RWM Stability

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Macroscopic Stability TSG
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Princeton Plasma Physics Laboratory

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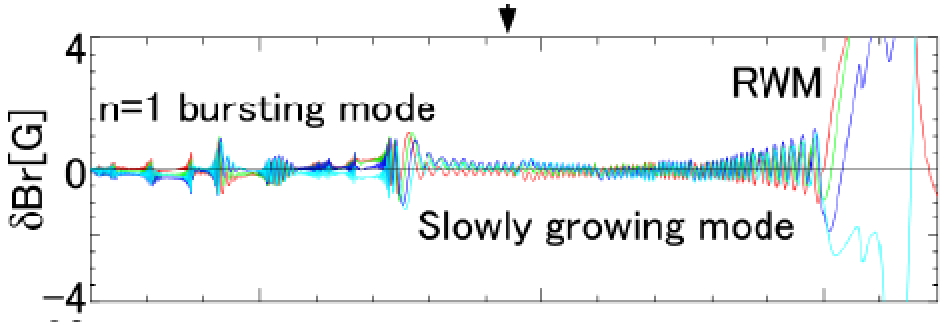
Motivated by observations of RWM triggers

- Motivation
  - Recent JT-60U results suggest changes in energetic particle distribution could be related to RWM destabilization.

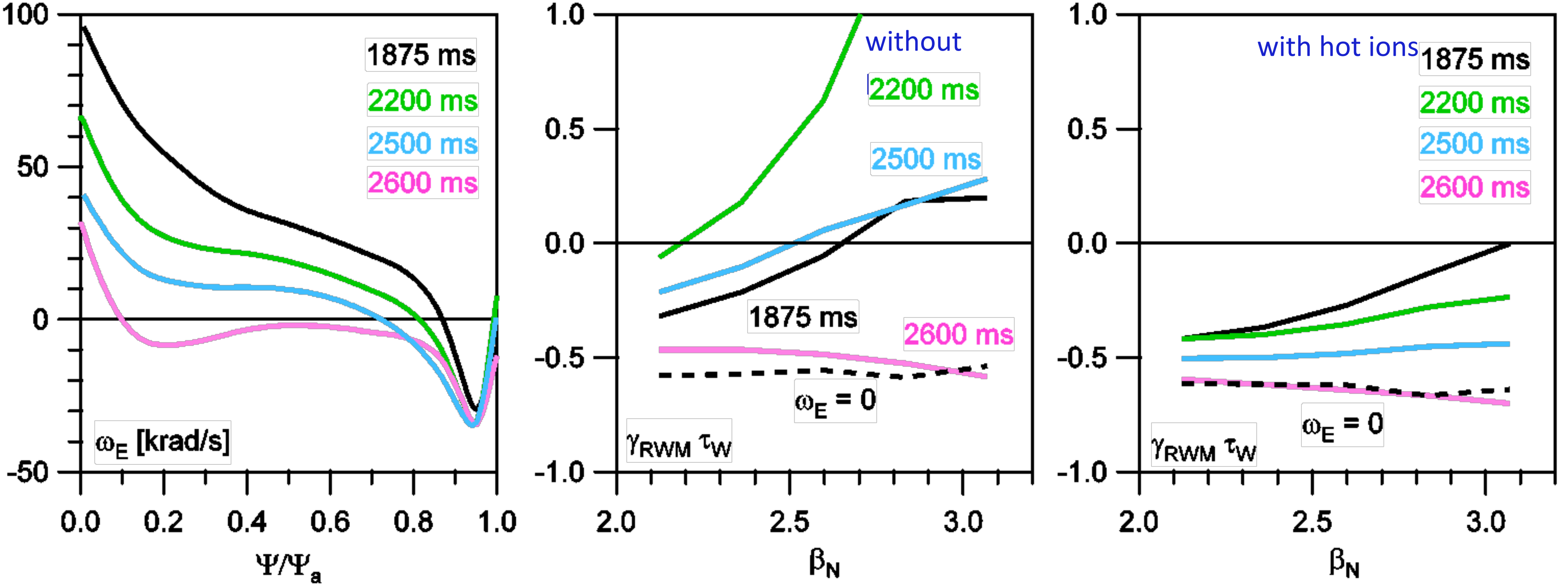


(Matsunaga et al., IAEA, 2008)

- Goals
  - Verify the theoretical understanding of how fast particles influence RWM passive stabilization physics.

Supports NSTX Research Milestone R(09-1): Understand the physics of RWM stabilization and control as a function of rotation.

Hot ions have a strongly stabilizing effect for DIII-D



– Using the equilibrium from DIII-D shot 125701 @ 2500ms and rotation from 1875-2600ms, MISK predicts a band of instability at moderate rotation without hot ions, but complete stability with hot ions.

– This could help to explain why DIII-D is inherently more stable to the RWM than NSTX, and possibly why energetic particle modes can “trigger” the RWM.

(Matsunaga et al., IAEA, 2008)

DIII-D is running a similar experiment (half day) on May 22?, 2009

Test effect of hot ions on RWM stability by reducing the (trapped) hot ion fraction (#289)

Description

- Reduce fraction of trapped hot ions with respect to reference (125701: (β_h/β=35% at n_e=3.7x10^{19}/m^3~0.4n_G, I_p=1.1MA)
- Evaluate changes in RWM stability by observing unstable mode or changes in the damping rate using active MHD spectroscopy

Experimental approach

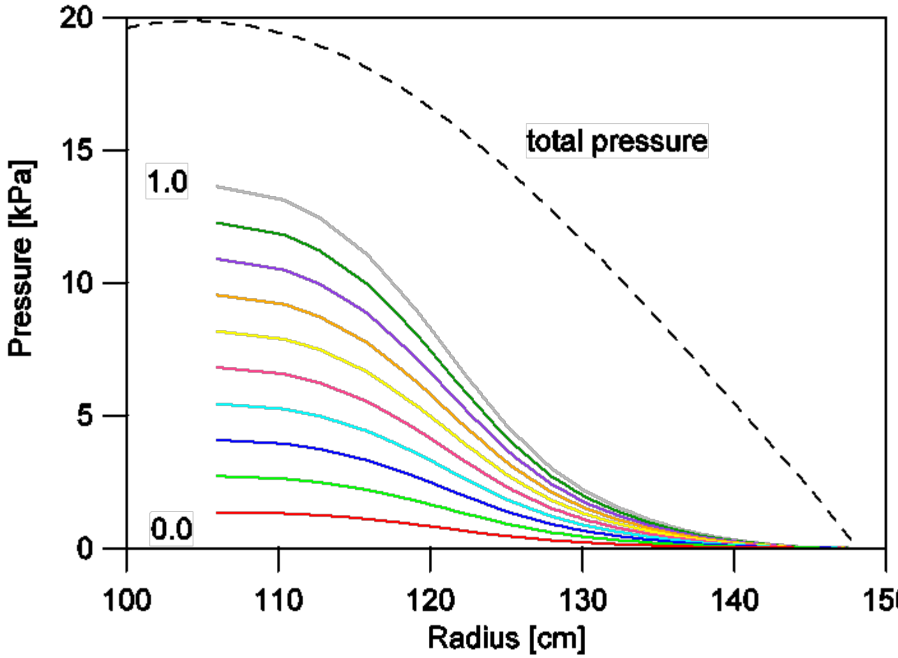
- Hot ion fraction depends on slowing down and energy confinement time

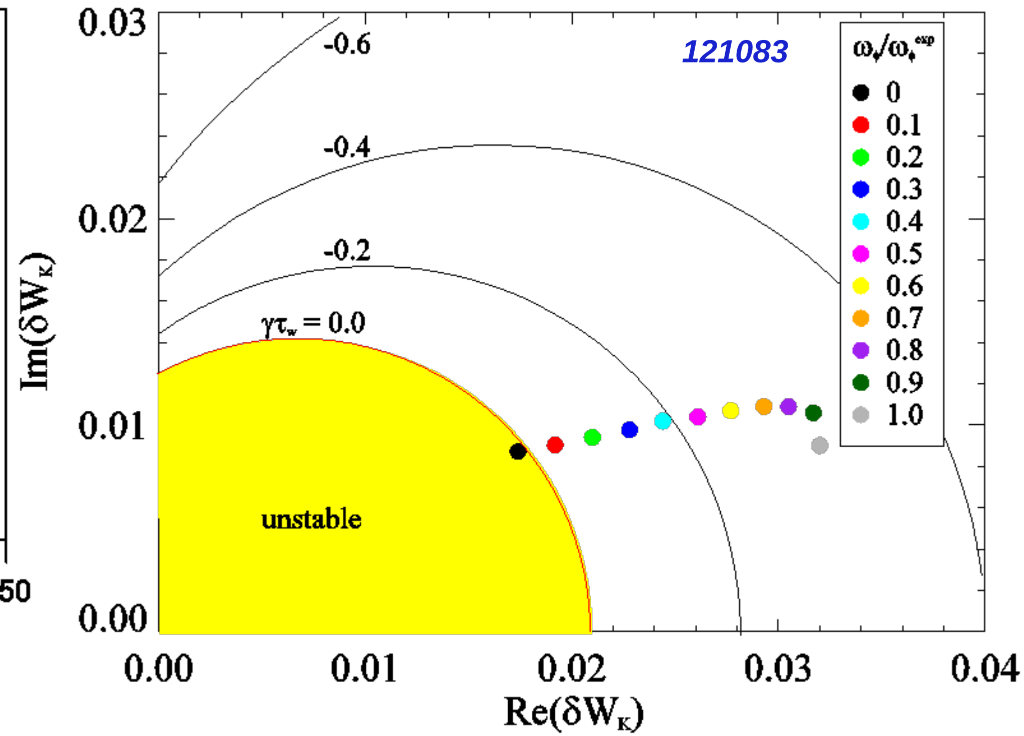
$$\frac{W_{hot}}{W_{th}} = \frac{\tau_h}{\tau_{E,th}}$$

→ Decrease slowing down time by increasing the density: $\tau_h \propto n_e^{-1}$
  - No cryo pumps, gas puffing, pellets
  - Increase plasma current (allows for higher n_e and increases $\tau_{E,th}$)
- Aim for high C_β at finite rotation to test RWM rather than NTM limit

H. Reimerdes, RWM Physics Working Group Meeting, March 20, 2009

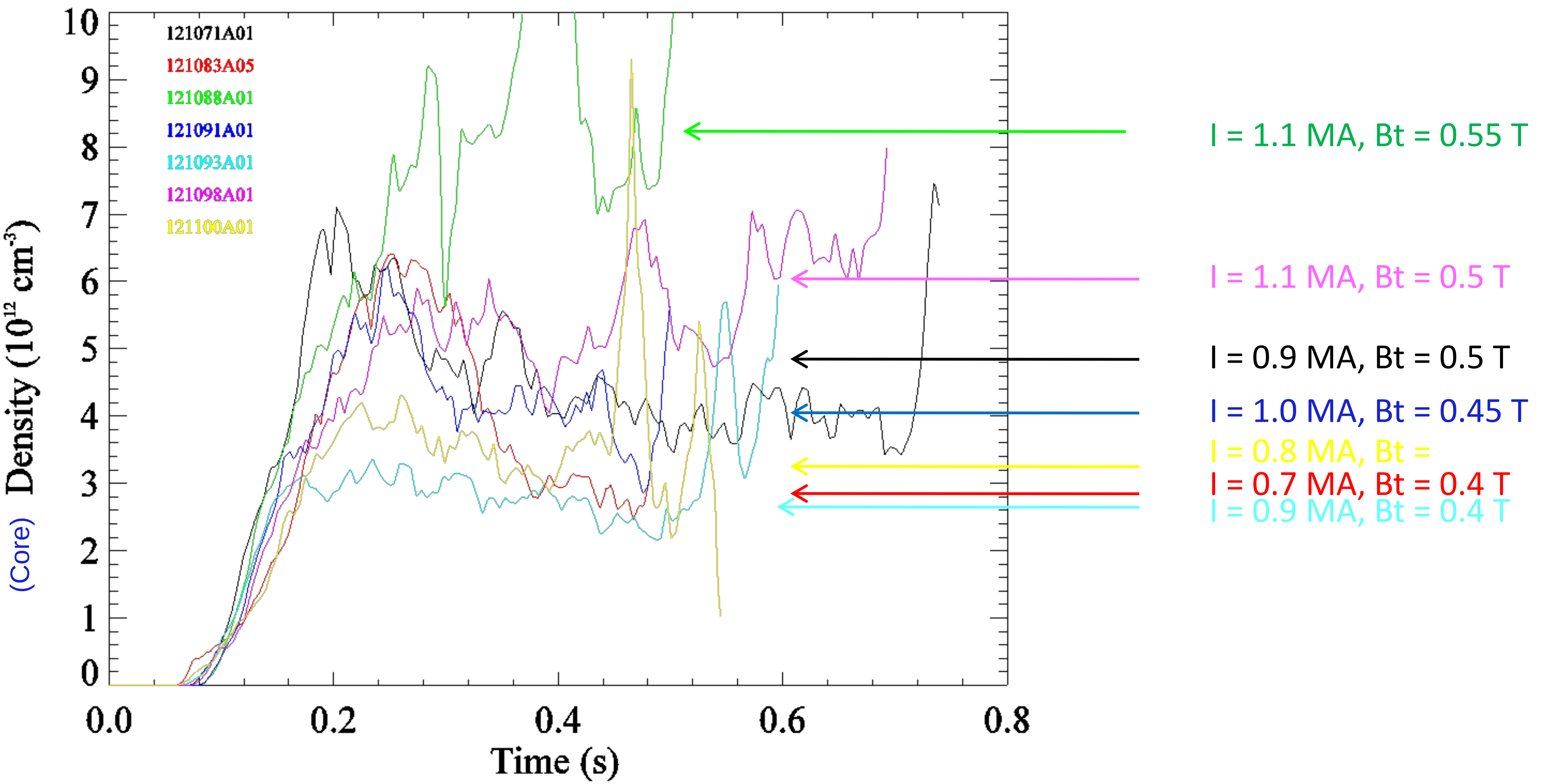
Initial calculations for NSTX showed a direct effect of hot ions on stability





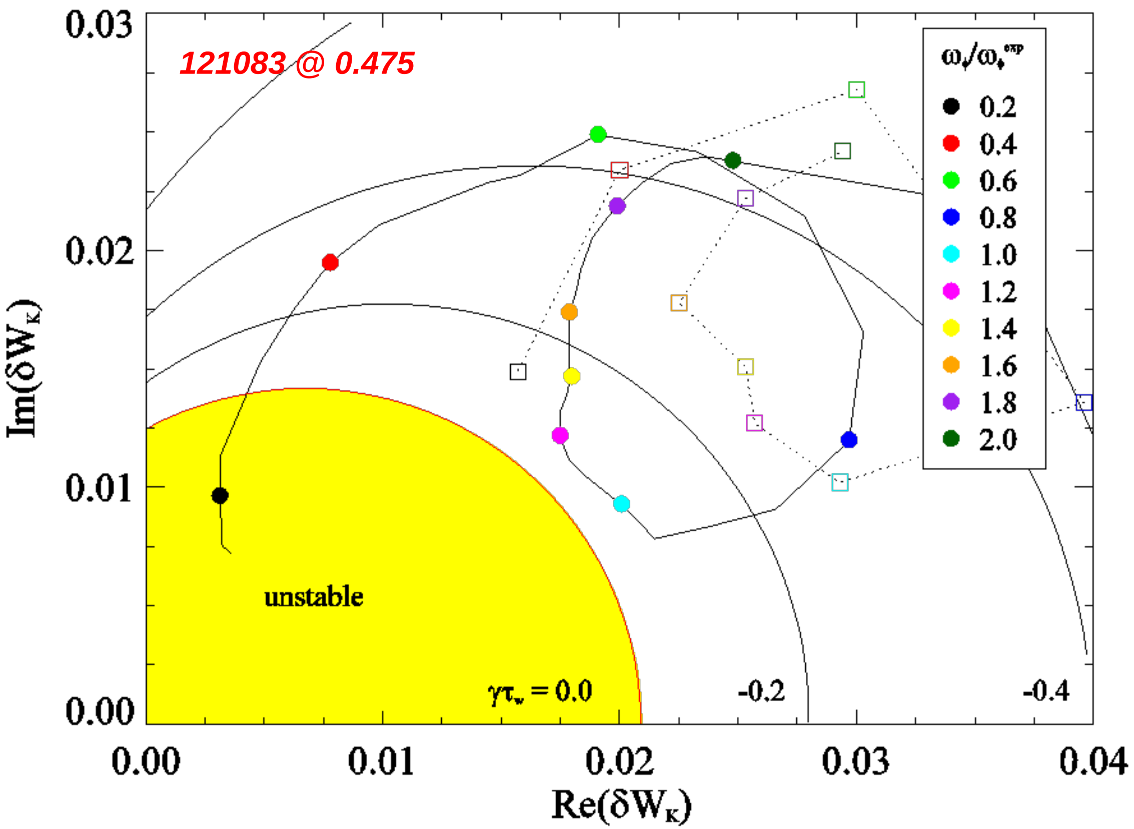
- Using a test profile for hot ion pressure (and density), we find a direct effect on the calculated growth rate.
- Because the hot ions are severely depleted near the edge in NSTX, the effect may be less than in DIII-D.

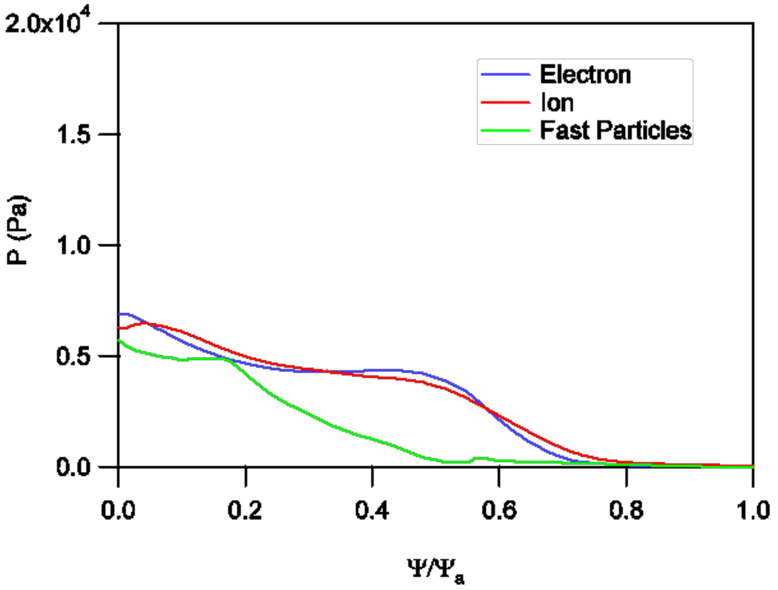
TRANSP analysis shows that a large range of fast ion density is possible



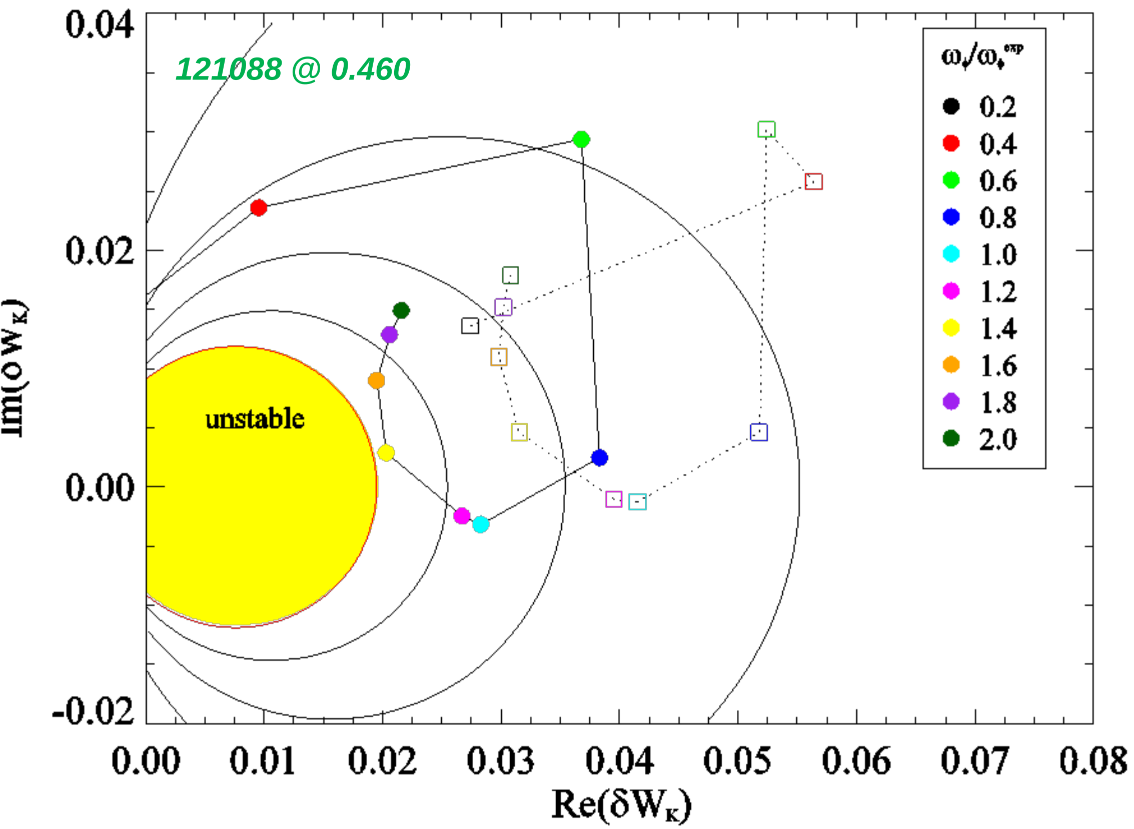
TRANSP hot ion density (and pressure) do correlate with plasma current and magnetic field. Is this difference enough to see in the stability calculation?

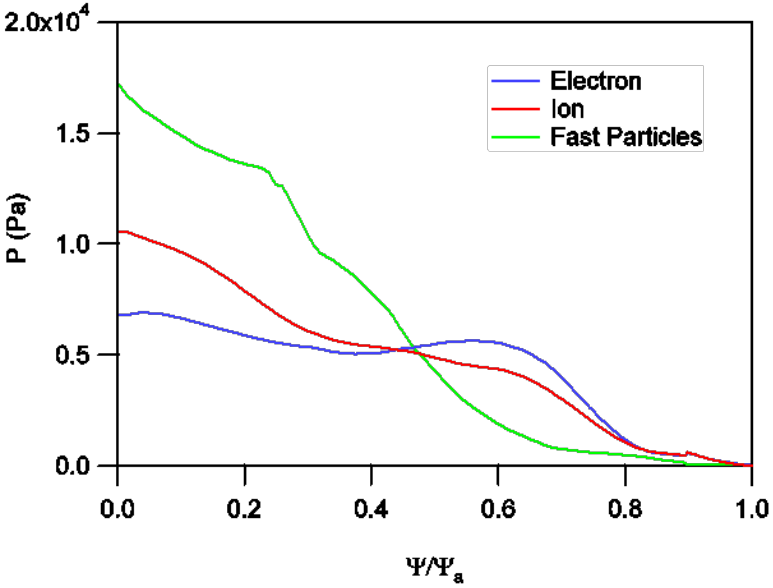
Including fast ions in MISK calculation leads to greater stability





Including fast ions in MISK calculation leads to greater stability





Shot Plan

Task	Number of Shots
1) Establish target	
A) Start lithium deposition	
B) Use XXXXXXX (something from this year) as setup shot (relatively high elongation ~ 2.3 to avoid rotating modes, I_p = 0.9 MA, B_t = 0.45T), start n=3 correcting field at 0.250 s, ramping to full amplitude at 0.300 s.	3
2) Vary the n=3 DC field timing and magnitude	
A) Correct n=1 error field using feedback system, B_p sensor filter time = 100 ms.	3
B) During the period devoid of n=1 rotating mode activity, vary the n=3 DC field from correcting phase to braking phase, and vary the SPA current ramp rate and timing to optimally change plasma rotation, to find the marginal point.	6

3) Vary the plasma current and toroidal field to change the fast particle density

Repeat the above procedure for the next two conditions, still with lithium.

Condition	Ip (MA)	Bt (T)	Shots
1	0.9	0.45	(already done above)
2	0.7	0.35	9
3	1.1	0.55	9

If the conditions can be completed quickly, we could add two more: I_p = 0.8 MA, B_t = 0.40T, and I_p = 1.0 MA, B_t = 0.50T, or we could move on to step four.

4) Passivate and repeat the above without lithium.	
This will effectively change the density (and density profile), thus changing the fast ion density profile as well. Could be another half day.	(27)
Total:	30+(27)

XP932: RWM Stabilization Physics - Diagnostics

- Required diagnostics / capabilities
  - Ability to operate RWM coils in n = 3 configuration
  - RWM sensors
  - CHERS toroidal rotation measurement
  - Thomson scattering
  - USXR
  - MSE
  - Toroidal Mirnov array / between-shots spectrogram with toroidal mode number analysis
  - Diamagnetic loop
- Desired diagnostics
  - FIReTip
  - Fast camera

Difference between hot and thermal ion calculations

Let us examine the difference between the trapped ion and hot ion contributions:

$$\delta W_K^{hi} = \sum_l \sqrt{2}\pi^2 \int \frac{d\Psi}{B_0} n_a \varepsilon_a \int d\Lambda \hat{\tau}_b^{hi} |\langle H^{hi} \rangle|^2 I^{hi}$$

$$\delta W_K^{ti} = \sum_l \frac{\sqrt{\pi}}{2} \int \frac{d\Psi}{B_0} n_i T_i \int d\Lambda \hat{\tau}_b^{ti} |\langle H^{ti} \rangle|^2 I^{ti}$$

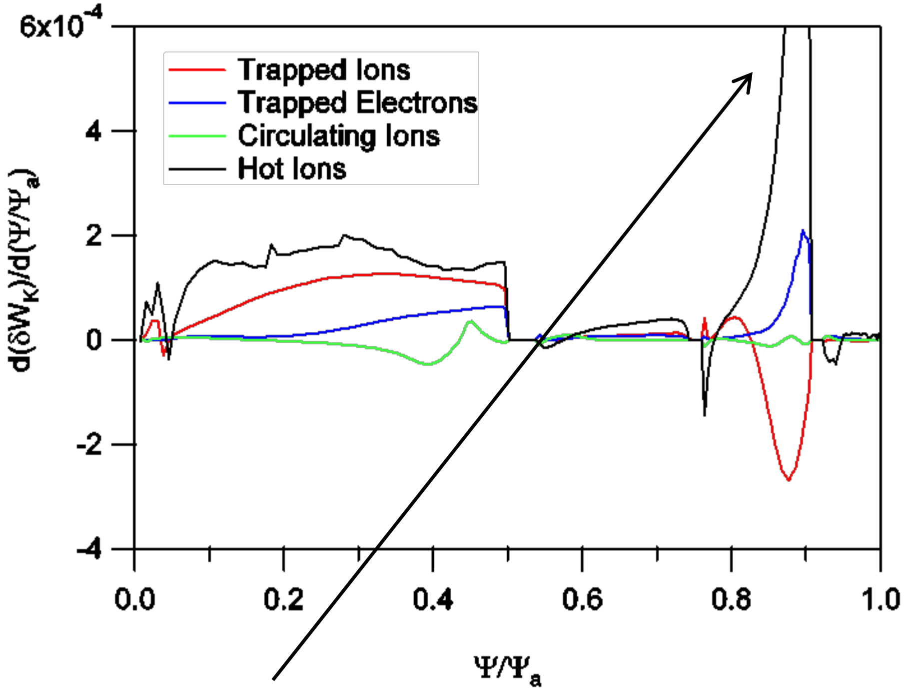
$$\frac{\delta W_K^{hi}}{\delta W_K^{ti}} \approx (2\pi)^{\frac{3}{2}} \frac{n_a}{n_i} \frac{\varepsilon_a}{T_i} \frac{I^{hi}}{I^{ti}}$$

large

small

large to very large, near edge

comparable magnitudes, but different Ψ distribution.



Large ε_a near the edge amplifies any hot ion energy integral contribution. For this not to happen, hot ion density near the edge would have to be very low.

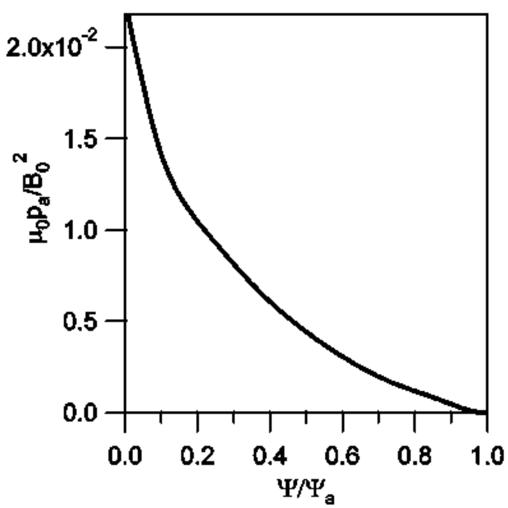
Inputs to the hot ion contribution

Given p_a and n_a, find ε_a, by iterating these three eqns.:

$$\varepsilon_a = \frac{p_a}{p_i}\frac{n_e}{n_a}\frac{\overline{\overline{T_i}}}{\overline{T_a}}$$

$$\overline{T_a} = \frac{2}{3}\left(\int \frac{\hat{\varepsilon}_a^{\frac{3}{2}}}{\hat{\varepsilon}_a^{\frac{3}{2}} + \hat{\varepsilon}_c^{\frac{3}{2}}} d\hat{\varepsilon}_a\right)\left(\int \frac{\hat{\varepsilon}_a^{\frac{1}{2}}}{\hat{\varepsilon}_a^{\frac{3}{2}} + \hat{\varepsilon}_c^{\frac{3}{2}}} d\hat{\varepsilon}_a\right)^{-1}$$

$$\hat{\varepsilon}_c = \left(\frac{3\sqrt{\pi}}{4}\right)^{\frac{2}{3}}\left(\frac{m_a}{m_i}\right)\left(\frac{m_i}{m_e}\right)^{\frac{1}{3}}\left(\frac{T_e}{\varepsilon_a}\right)$$



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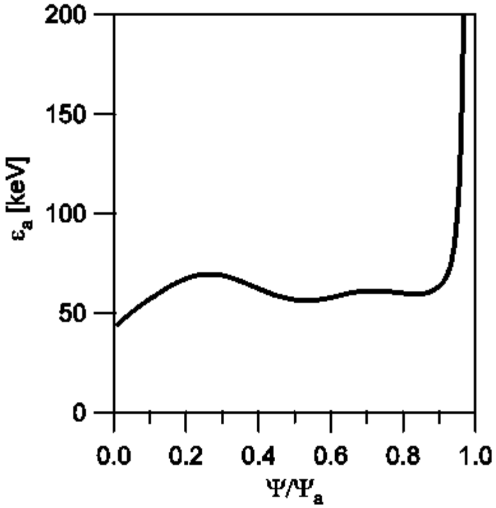

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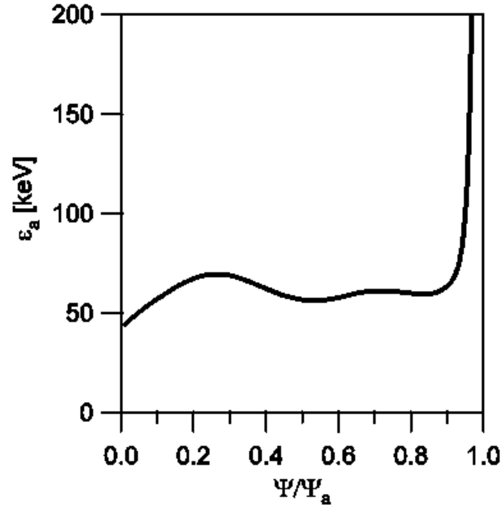
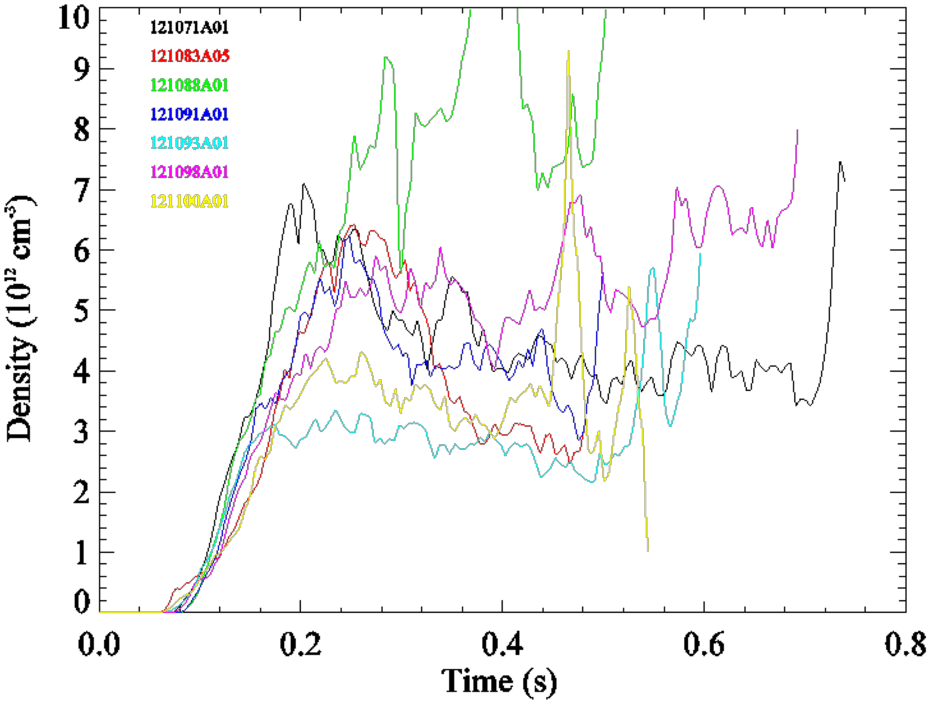
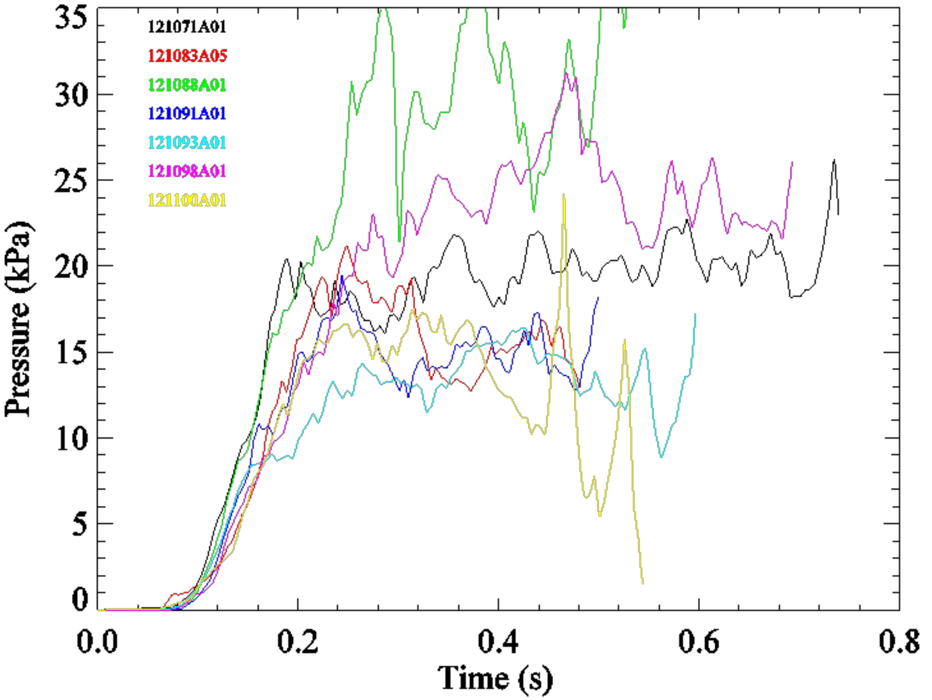


result*

* note that the rise at the edge is due to n_a going to zero faster than p_a. This didn't affect the results in this case (see $\Psi > 0.9$ on plot on next page), but it is something to pay attention to.

Density and Pressure





RWM Stabilization Physics – influence of fast particles

- Approach
  - Use TRANSP beforehand to identify a range of fast ion profile shots.
  - Establish RWM target shots.
  - Use plasma current and density as control knobs for changing the fast ion density and pressure profiles.
    - I_p from 0.6 – 1.2 MA.
    - Scan toroidal field at constant q to change density.
  - Use TRANSP analysis between shots?