

# Energetic Particles Break-Out Session

## Unedited Summary

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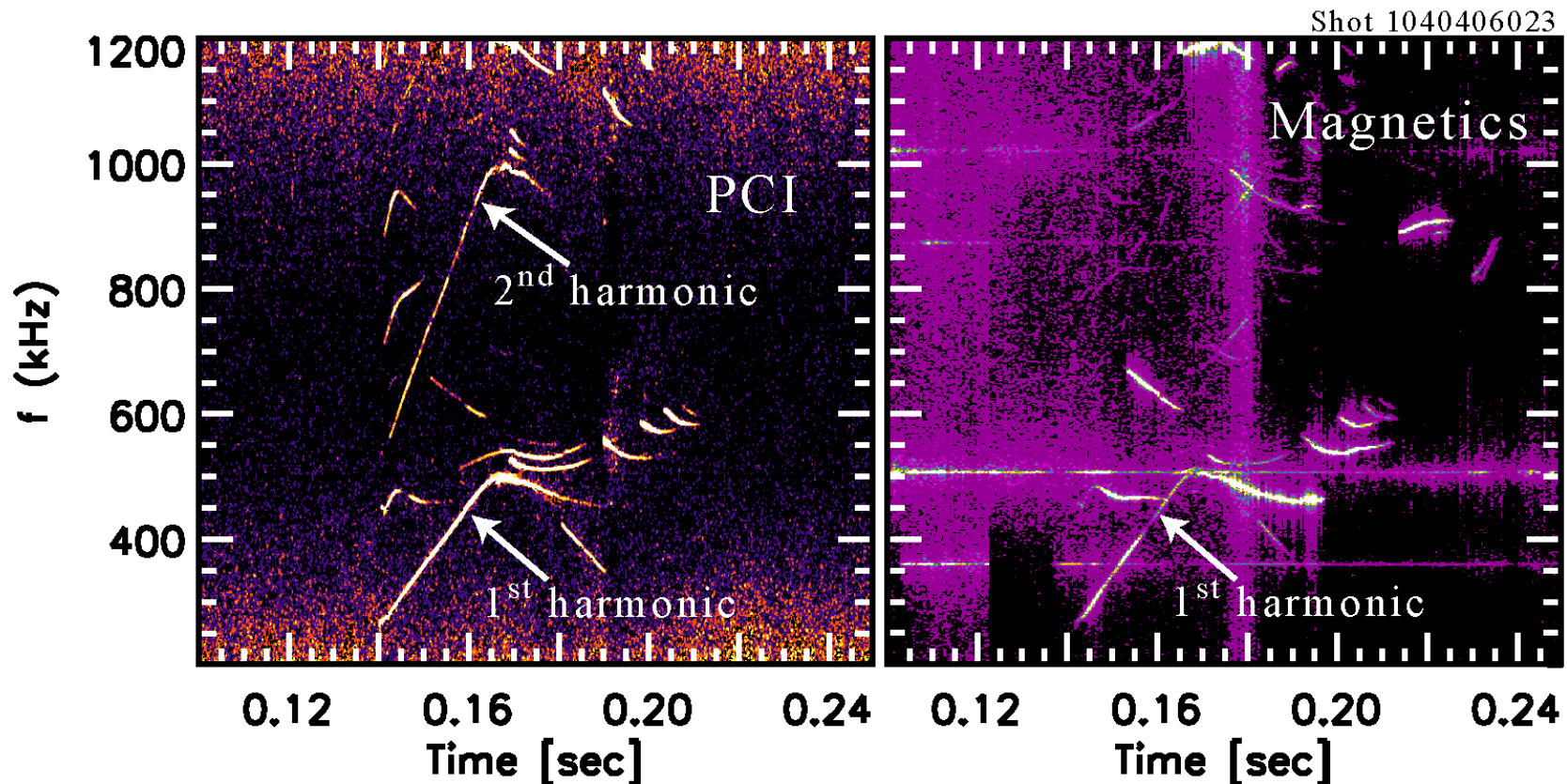
Based on 1 plenary talk, 14 topical presentations, remote participation from Culham Laboratory, and informal discussions

# A. Recent Developments in Energetic Particles

What major BP-related developments (in theory, modeling, experiment and technology) have occurred in the energetic particles area since the Snowmass 2002 study?

- Alfvén cascades – measurements, theory, and modeling are reasonably well understood – lead to measurements of  $q(r)$
- Improved modeling of AE damping mechanisms
- Qualitative experimental verification of nonlinear single mode physics
- Emerging self consistent nonlinear simulations of energetic particle dynamics in the presence of multiple unstable modes
- Significant advances in core fluctuation diagnostics (PCI, interferometry, reflectometry, ...)
- 2D  $\gamma$ -ray diagnostic measures high energy ion profiles

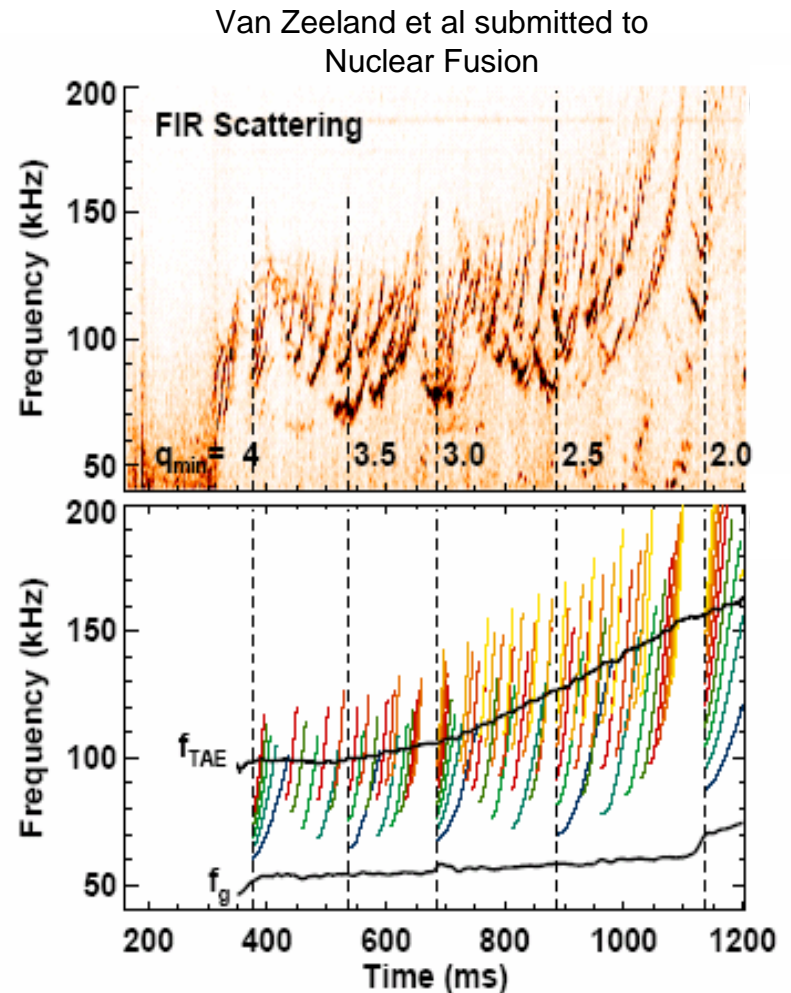
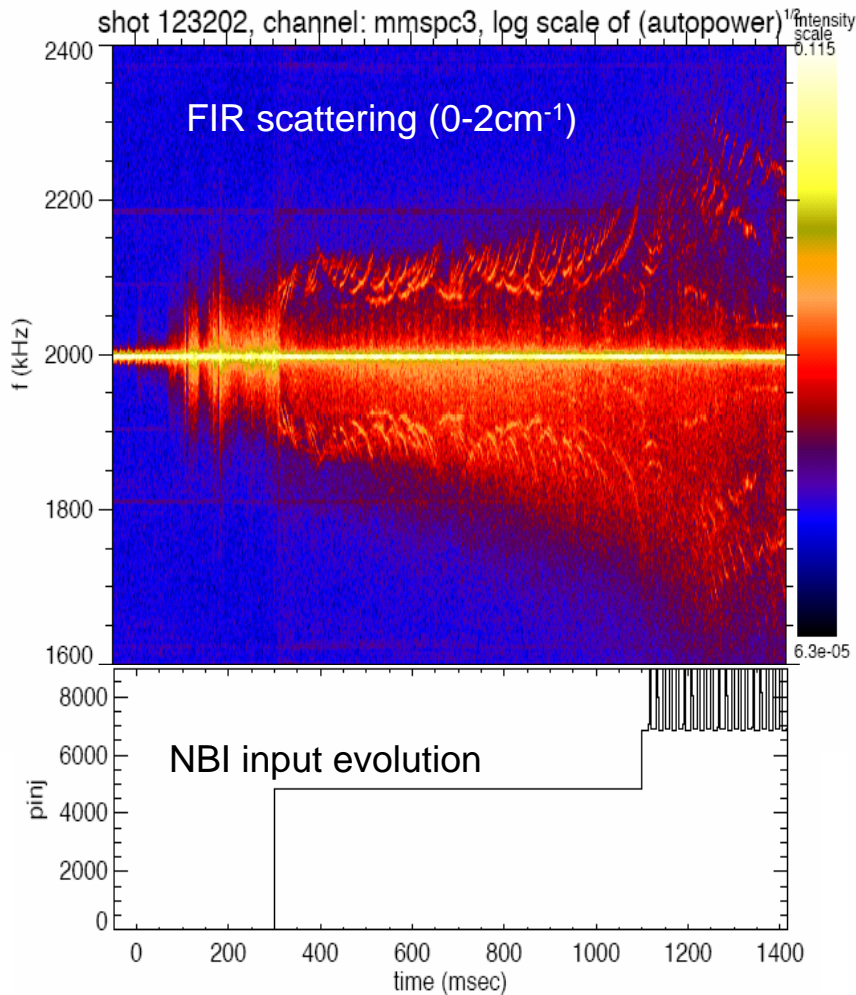
## 2<sup>nd</sup> Harmonic Indicates Alfvén Cascades are Nonlinear



- 2<sup>nd</sup> harmonic AC's on PCI with  $f_{2\text{nd}} = 2 \times f_{1\text{st}}$  and  $A_{2\text{nd}} = A_{1\text{st}}/10$
- Not clearly visible on the magnetic pickup coils at the wall
- Indicates nonlinear excitation of ACs as expected by theory

# Observation of RSAE activity in DIII-D

Neutral beams injected during current ramp to create reverse shear profile with increasing beta. Toroidal rotation and  $q_{\min}$  evolve in time. RSAEs observed repeatedly as  $q_{\min}$  evolves.

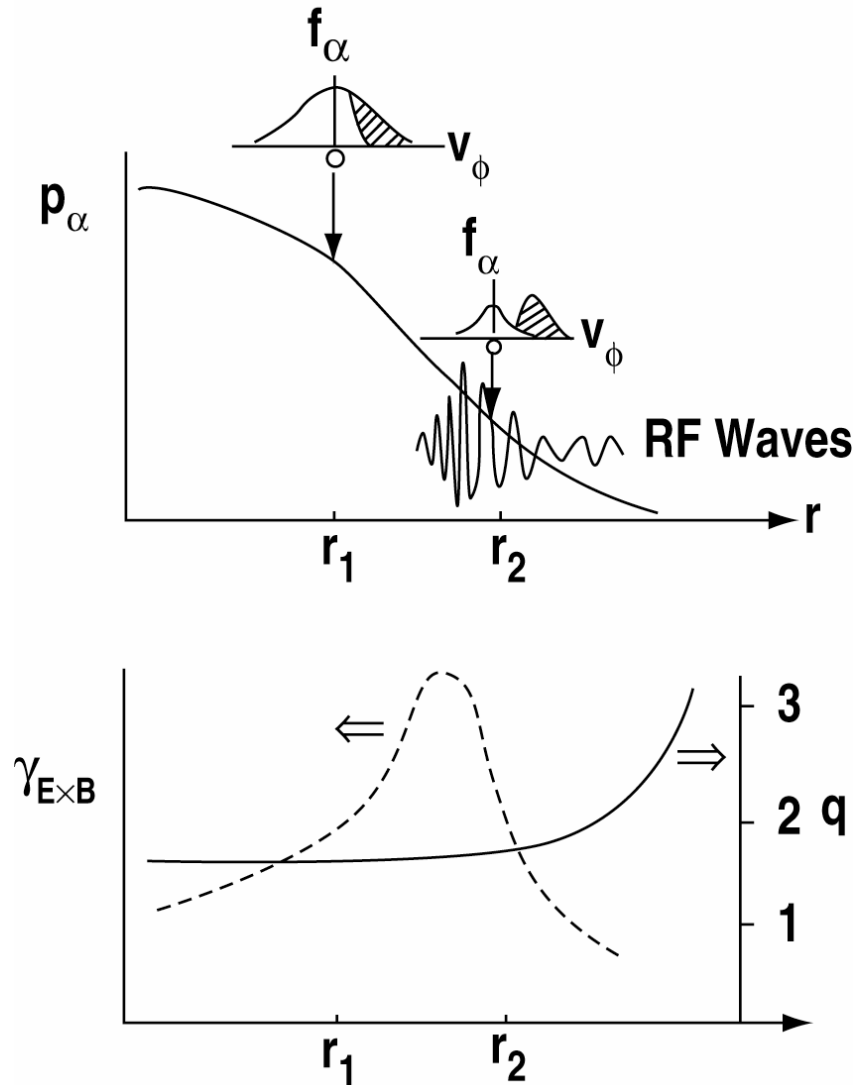


# B.1. Implications and Outstanding Issues

What energetic particle issues remain to be resolved for a successful BP experiment in ITER?

- Control fast ion losses in present devices
- Interpret present experiments and model them quantitatively
- Integrate energetic particle physics with
  - MHD
  - Transport
  - Current Drive
  - Burn dynamics
- Improve confinement with fast ion redistribution

# Use the $\alpha$ s and RF waves to create ITBs



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- Improve confinement with fast ion redistribution
- Understand fast electron behavior including runaways
  - Do runaways generate collective instabilities?
- Further develop diagnostics for
  - Fast ion distribution in phase space
  - Lost fast ions
  - Energetic particle driven modes (fishbones, AEs, ion cyclotron modes)
- **Generate interest for creative young people to enter the field**

## B.2. Implications and Outstanding Issues

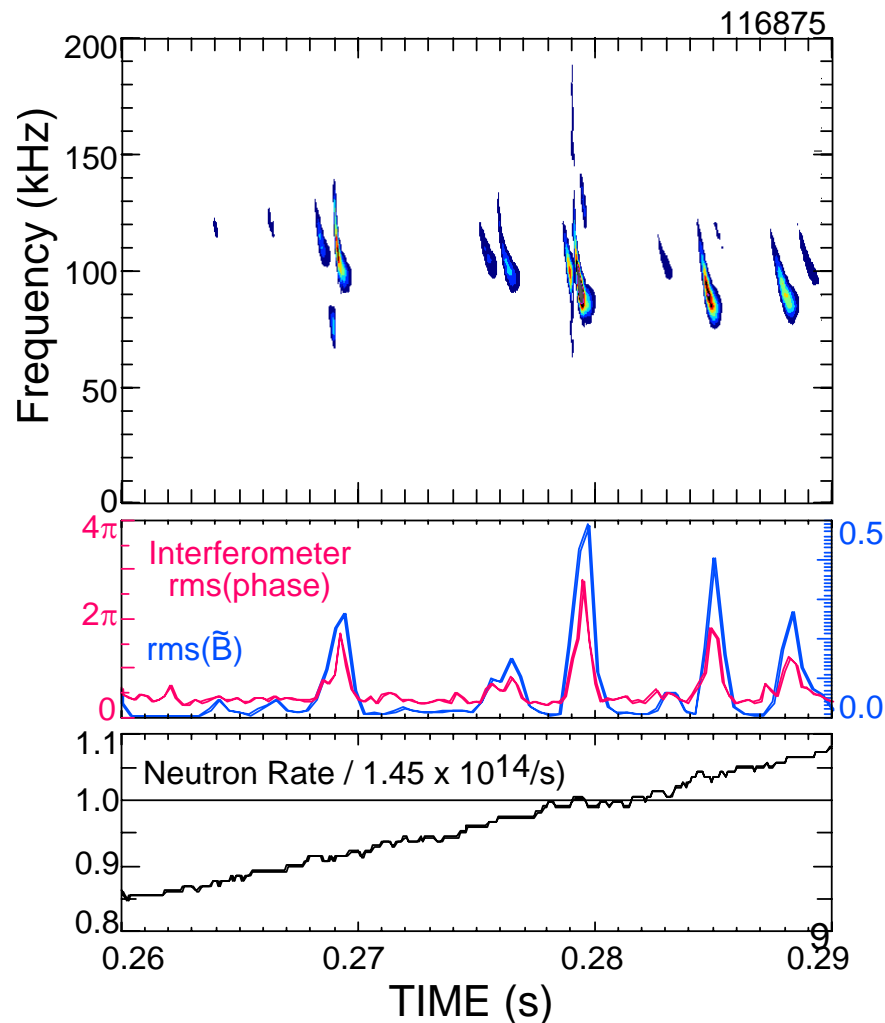
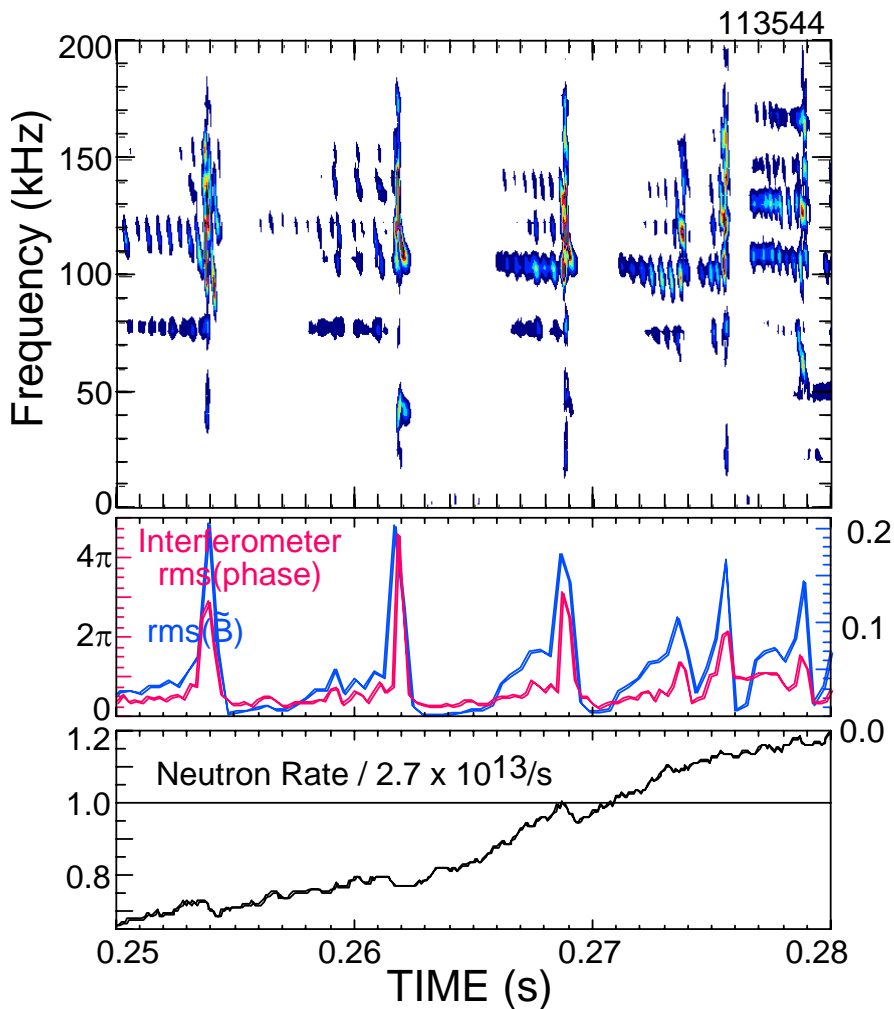
What are the consequences of resolving these energetic particle issues in the next ~10 years?

- Safe navigation in the ‘sea of Alfvén eigenmodes’
  - Robust scenarios for fusion burn
  - Reduced risk of first wall damage
- Credible physics basis for reactor extrapolations

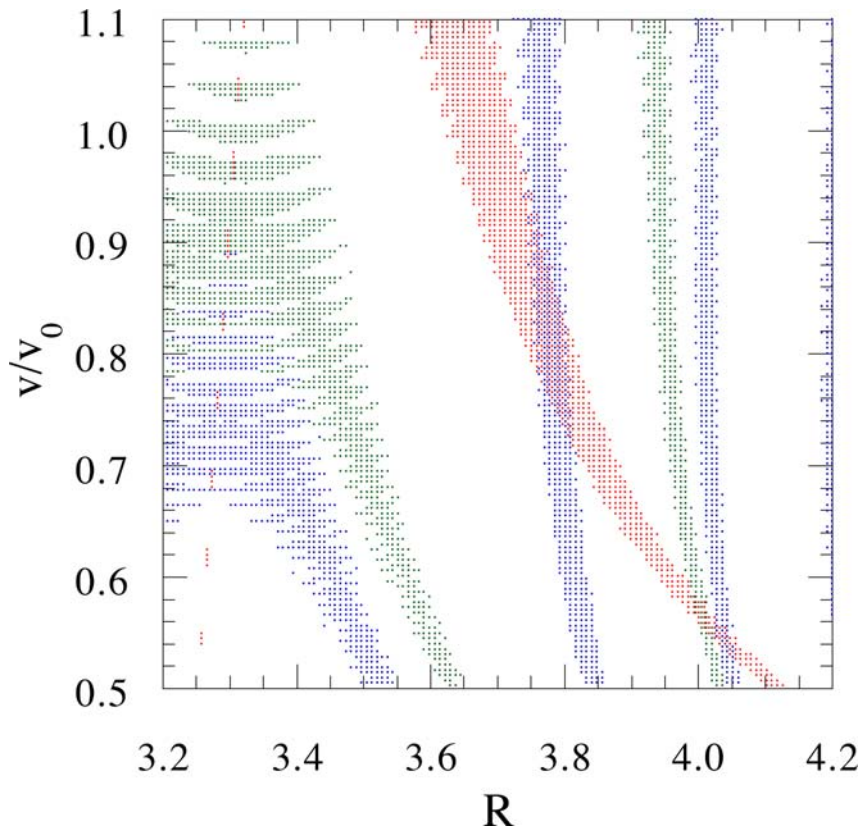
# Larger losses at strong, multi-mode bursts. weak losses single mode bursts



- Opportunity to examine multi-mode aspect fast ion transport



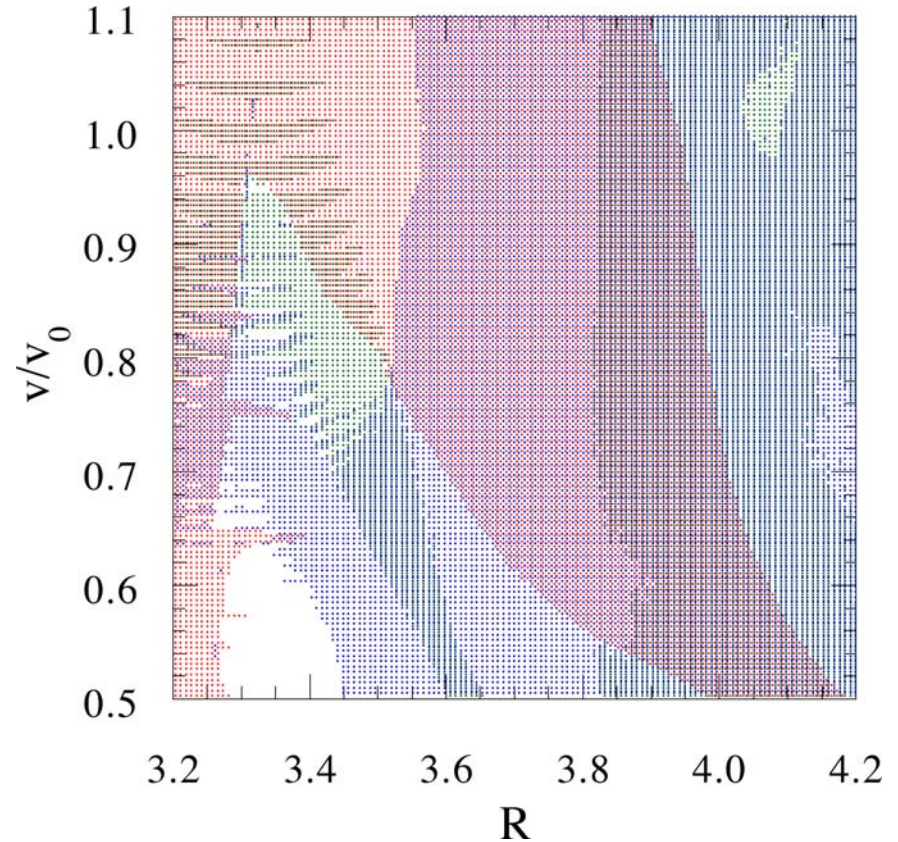
# Overlapping Phase Space Resonances



**For low amplitude modes:**

$$\delta B/B = 1.5 \times 10^{-4}$$

$n=1$ ,  $n=2$ ,  $n=3$



**At mode saturation:**

$$\delta B/B = 1.5 \times 10^{-2}$$

$n=1$ ,  $n=2$ ,  $n=3$

## B.3. Implications and Outstanding Issues

What energetic particle issues should be resolved by a successful BP experiment?

- Achieving self-sustained burn
- Achieving tolerable wall loading from energetic particles
- Understanding the impact of energetic particle instabilities on plasma performance
- Ability to predict, diagnose, and control energetic particle behavior

# What contributions can/should the U.S. fusion program make to resolve energetic particle issues in burning plasma experiments?

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- **Use existing experiments to study energetic particle effects and test control schemes**
  - ICRF and NBI generated fast ion driven Alfvén eigenmodes
  - Active MHD Alfvén eigenmode damping experiments
  - Support experiments aimed at measuring energetic particle distributions
- **Further develop energetic particle diagnostics**
- **Convert linear codes to user-friendly tools**
- **Develop predictive numerical models:**
  - Use flexible reduced codes to probe essential physics mechanisms
  - Move toward realistic integrated modeling of energetic particle behavior in burning plasmas
- **Blend energetic particle physics with bulk plasma behavior**
  - Plasma transport, flows/torques, etc.
- **Enhance our national and international collaborations**

## C.2. What should the US fusion community do?

How should the BPO be structured to best help the community make these contributions?

- Promote fundamental physics research related to burning plasmas
- Be responsive to fusion technology challenges
- Encourage broad participation especially of young scientists
- Instill an atmosphere of cooperation – team spirit
- Promote international collaboration on burning plasma research
- Focus on doing science rather than managing it