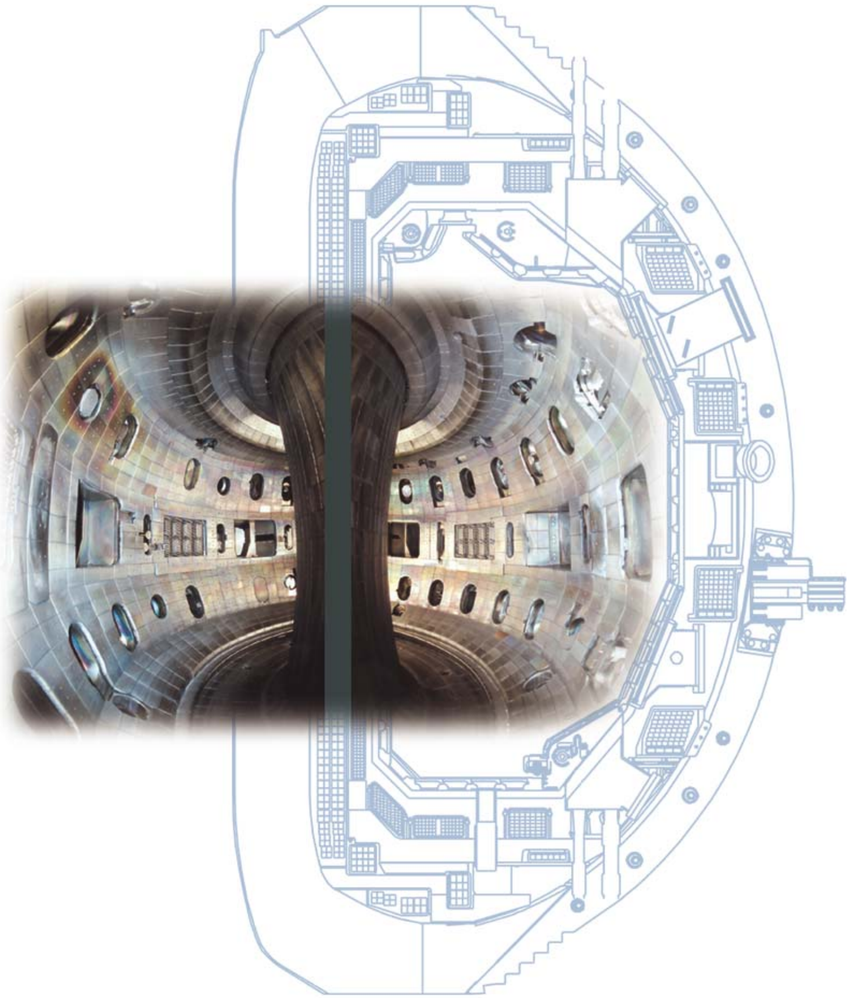
Core Barrier Formation Near Integer q Surfaces in DIII-D

Presented by
M. E. Austin



Presented at the
47th APS-DPP Meeting
Denver, Colorado

October 24–28, 2005

DIII-D
NATIONAL FUSION FACILITY
SAN DIEGO

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RESEARCH CENTER
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In collaboration with

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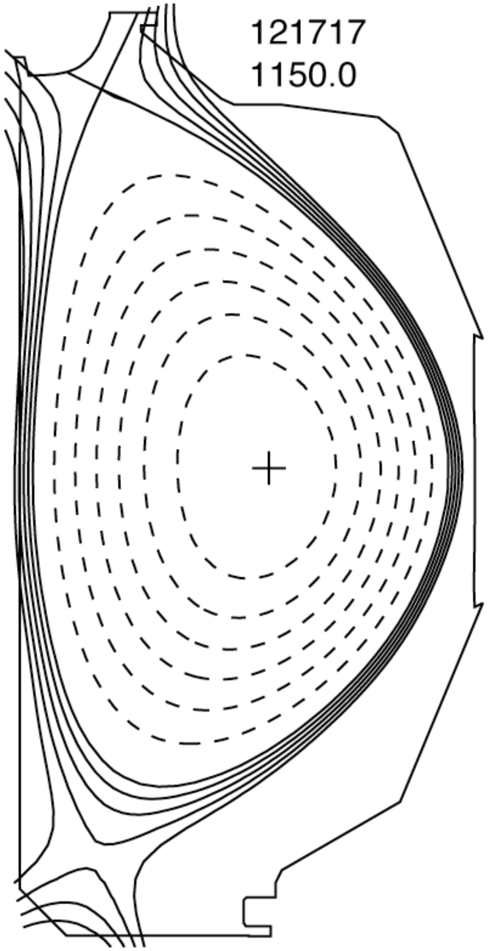
Motivation

- In tokamak devices it has been found that low order rational *q* surfaces play a key role in the formation of internal transport barriers (ITBs)
- Most often seen in negative central shear discharges at low power as q_{min} reaches integer value
- Proposed mechanisms for barrier formation include
  - MHD events that modify ExB flow shear
  - Inherently low transport adjacent to low m/n surfaces
- Detailed measurements of transport, turbulent fluctuation levels, and E_r are available — we can solve this problem

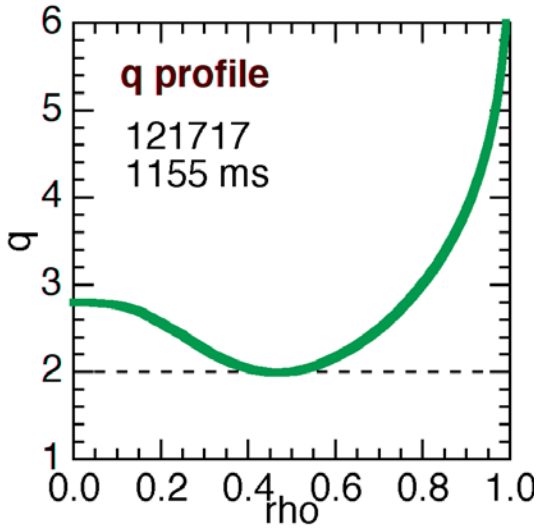
Summary of Results

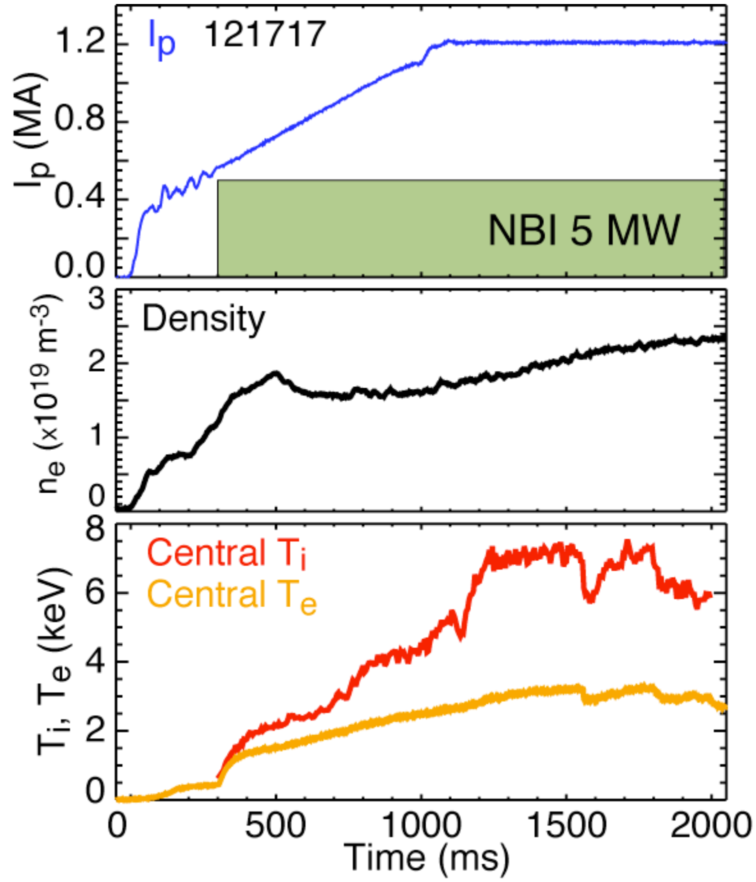
- Confinement improvement *precedes* the time of crossing an integer *q* surface and is symmetric in an interval around that event; core tearing modes are ruled out as a triggering mechanism
- Electron and ion transport reduction is transient in the neighborhood of integer *q* values at low power. At higher power a core ion transport barrier generally forms near the time of q_{min}=2
- Low and intermediate k turbulent fluctuations are seen to drop around integer *q*; intermediate k turbulence remains at reduced levels during the ITB phase
- T_e gradient measurements are in agreement with preliminary results from the GYRO code that implicate time averaged zonal flow structures tied to rational *q* surfaces as being part of the triggering process.

Core barrier triggering studied near marginal conditions



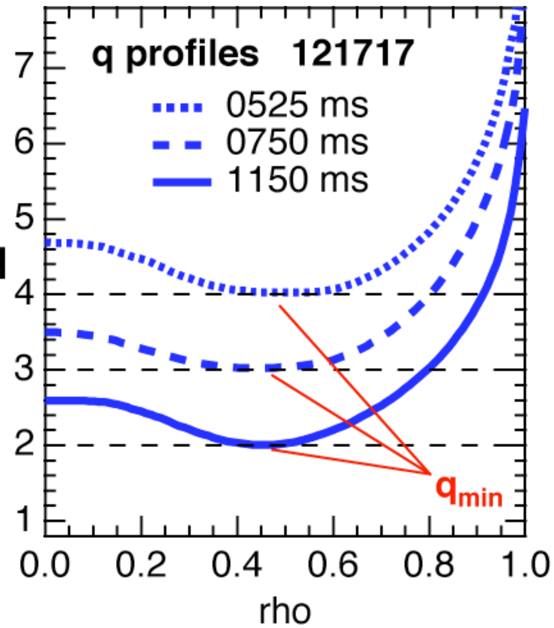
- Early NB heating in current ramp-up generates NCS
- Low power (2–5 MW) is used for q-triggered cases

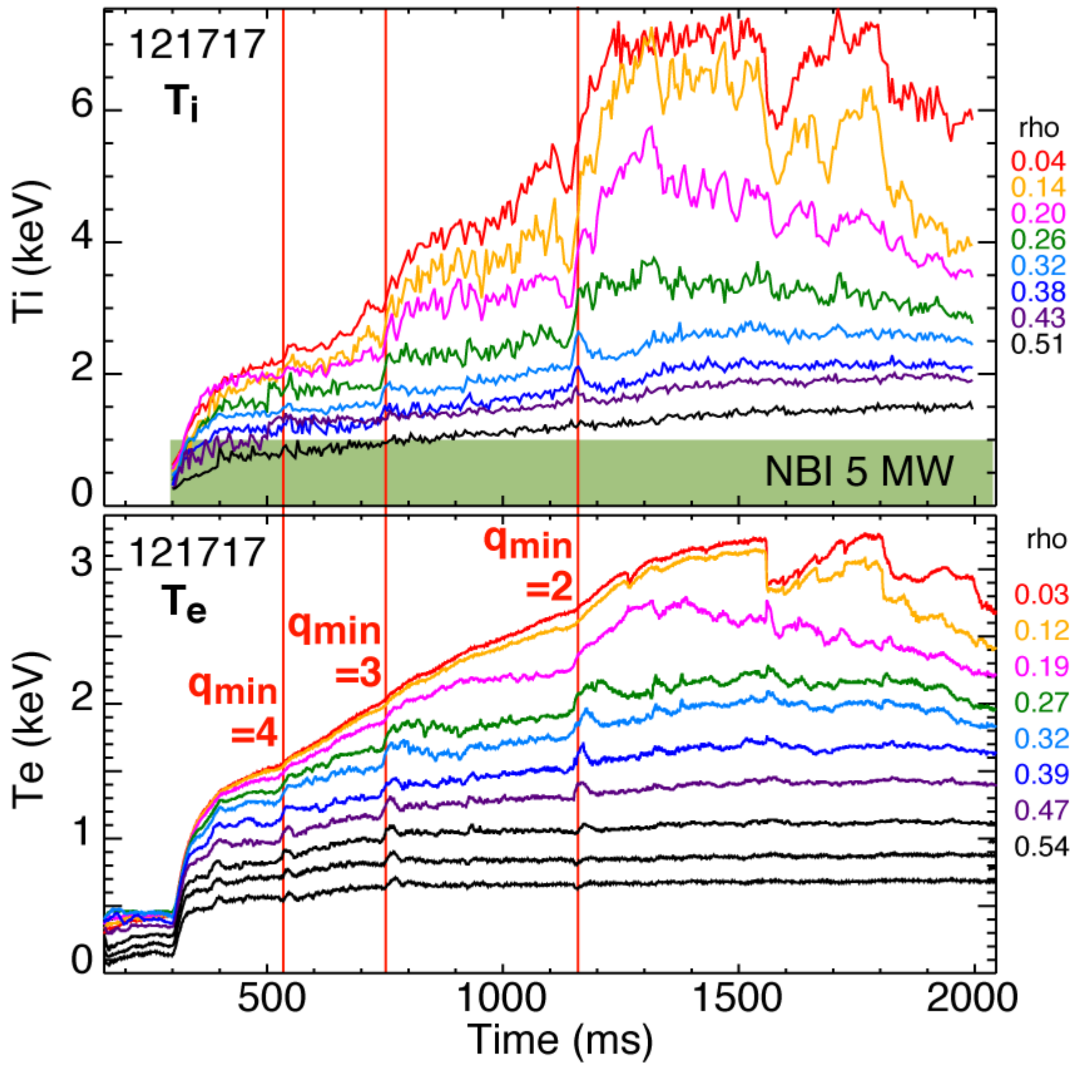




Changes in transport seen in DIII-D as q_{min} traverses integer values

- Persistent core barrier forms in T_i after 1200 ms, triggered at q_{min}=2 crossing

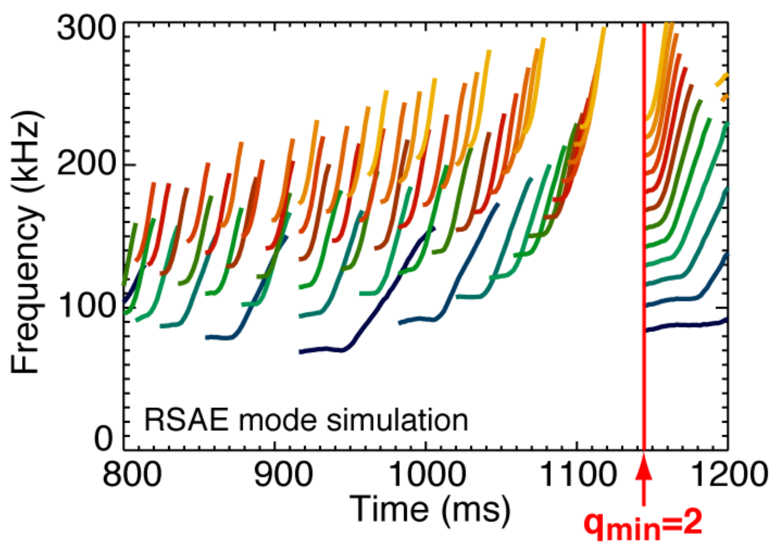


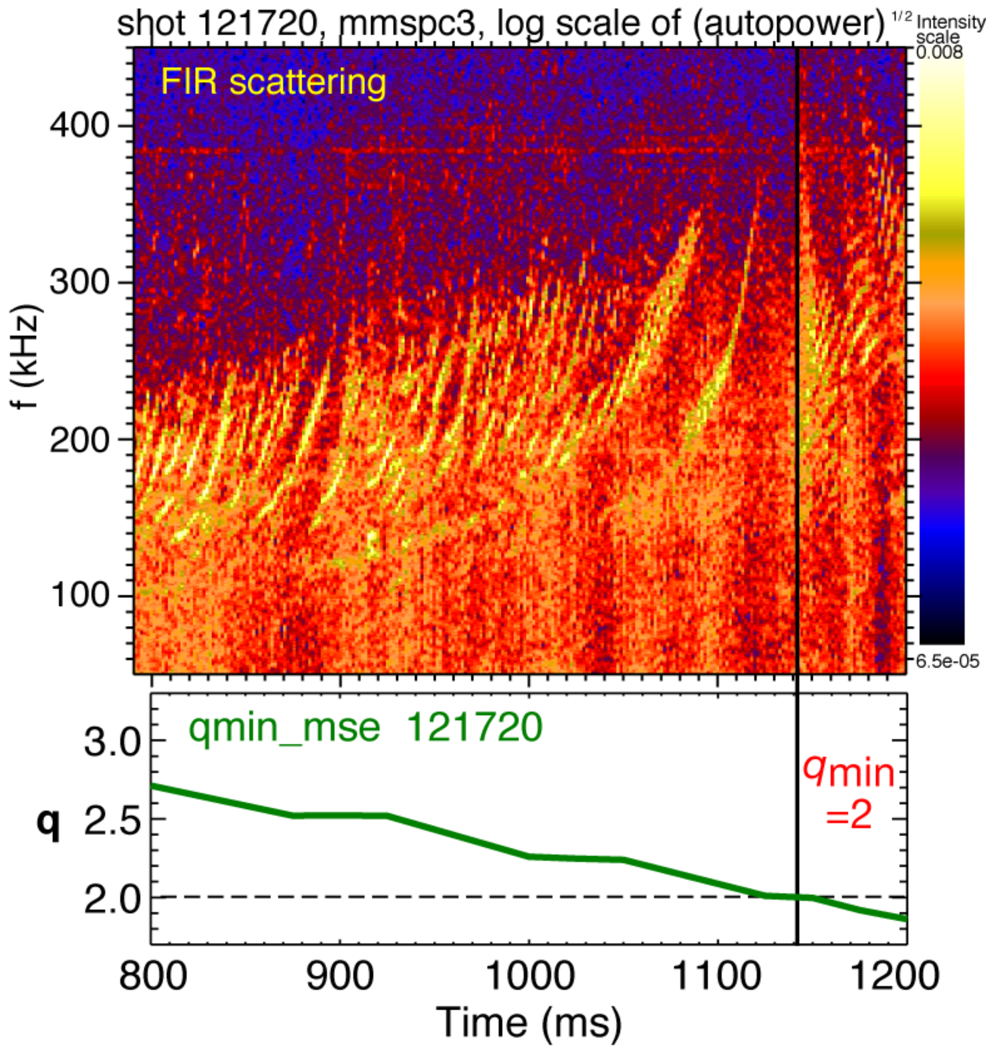


Integer q_{min} time is determined accurately from Alfvén cascades

- RSAE – Reverse shear Alfvén eigenmodes (cascades) are visible in FIR scattering data
- q_{min} vs time obtained from MSE-EFITs and cascades

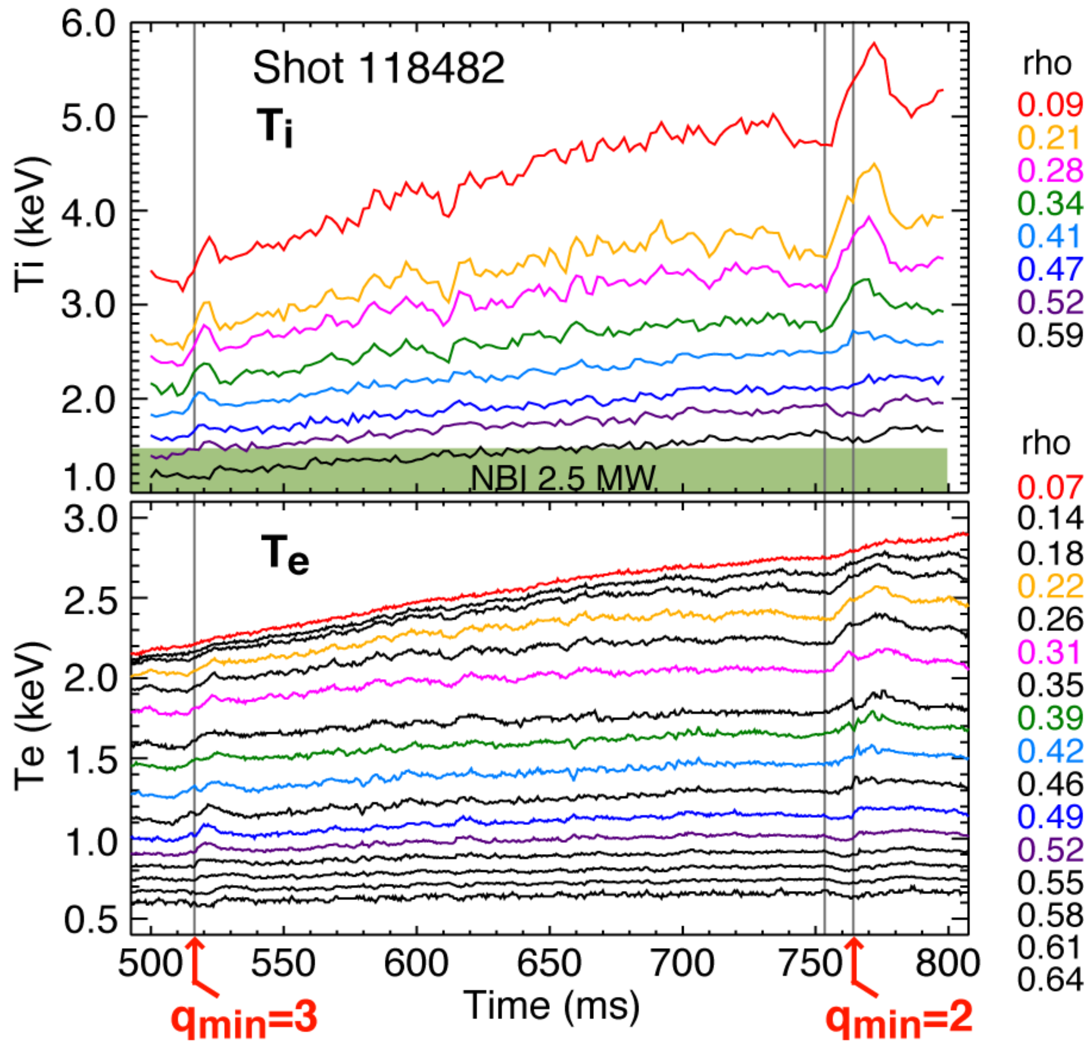
R. Nazikian, et al, Proc. 20th IAEA Fusion Energy Conf. (Vilamoura, Portugal, 2004)





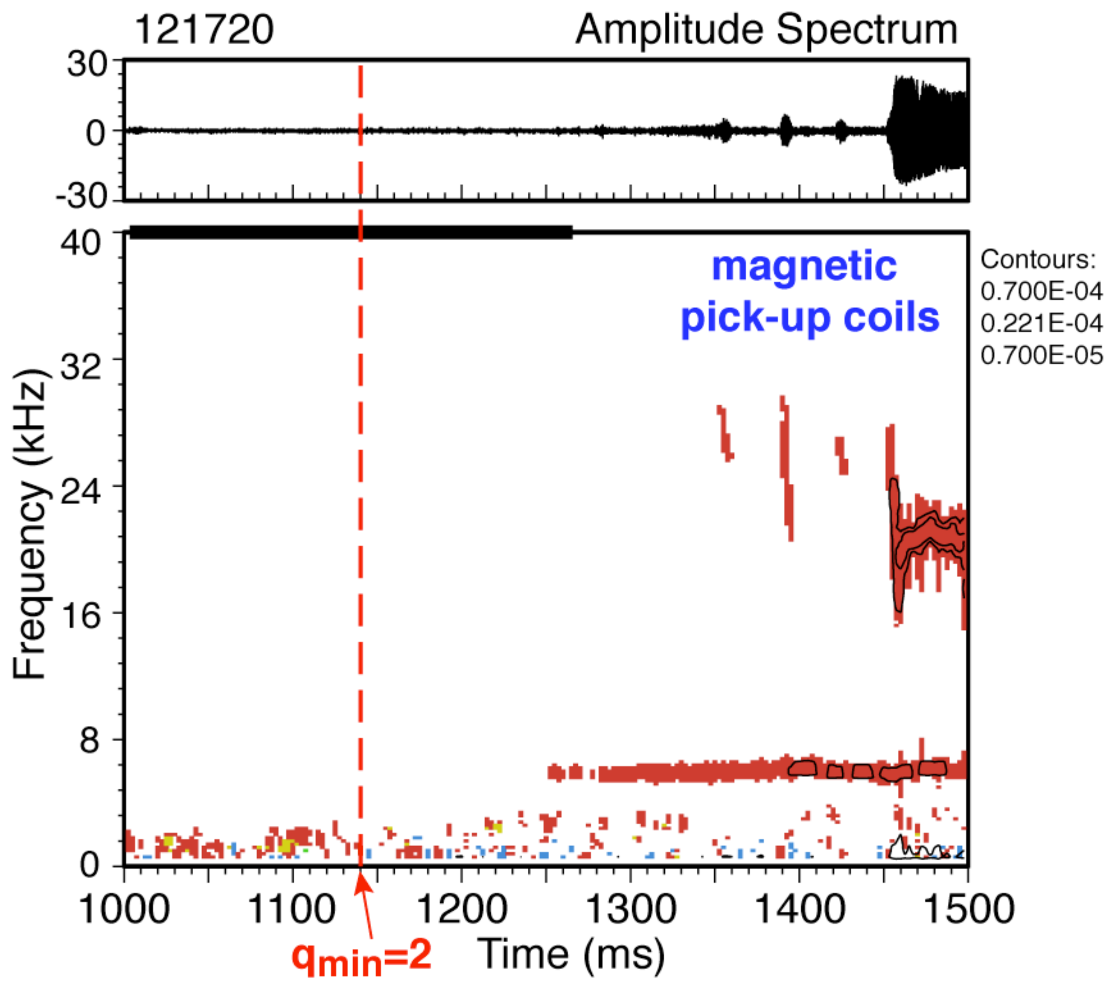
Transport improvement precedes appearance of rational surface

- Lower NB power (2.5 MW) produces transient confinement improvement
- Temperature rise starts 10-12 ms before q_{min}=2
- T_i ,T_e rise continues for a similar interval afterwards



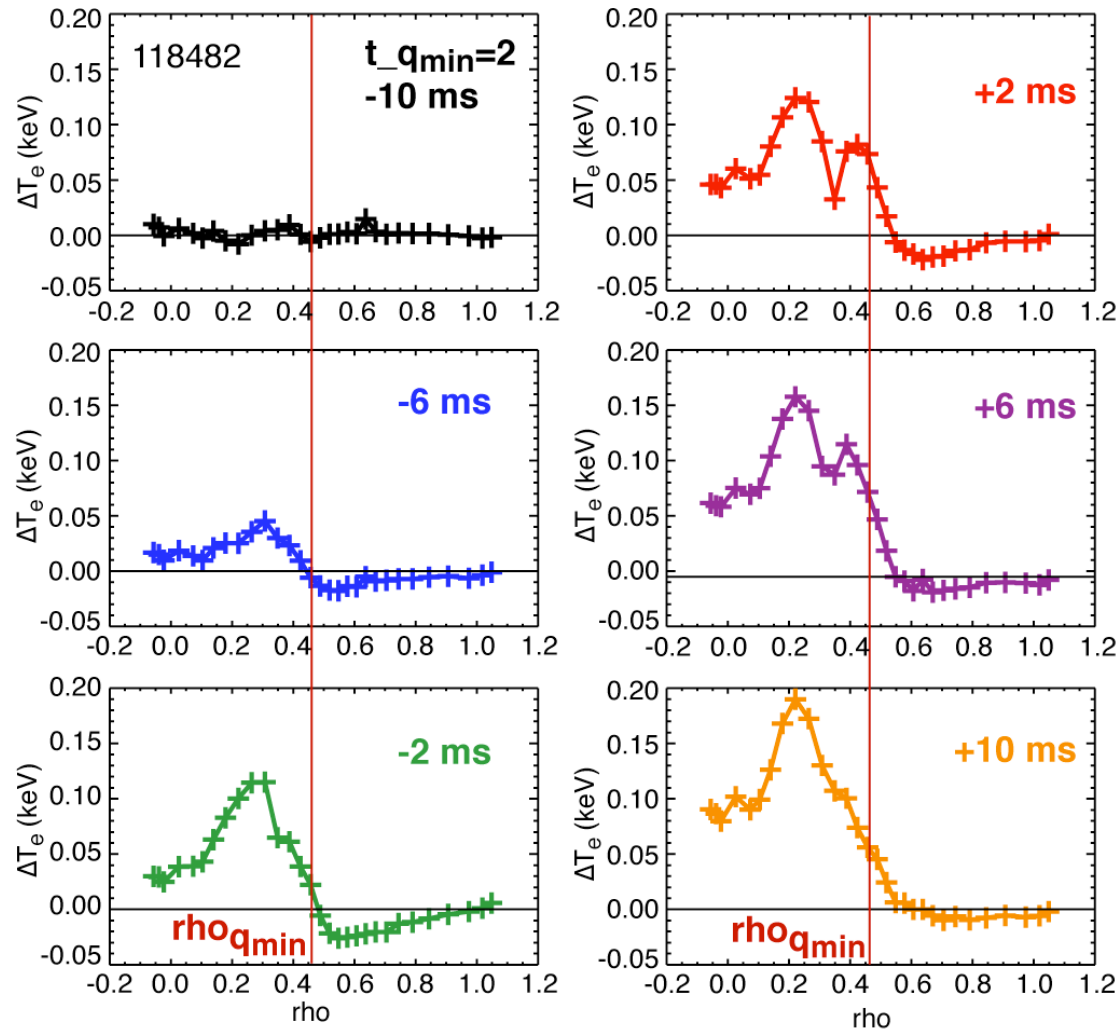
Reconnection and island formation not seen as trigger

- **Transport changes preceding integer q_{min} is primary evidence**
- Generally no modes detected on magnetics near q_{min}=integer time
- Modes appear later as beta increases



ΔTe change shows definite barrier signature

- ΔTe profiles referenced to 14 ms before q_{min}=2 time
- Dipole change in T_e oberved about q_{min} radius



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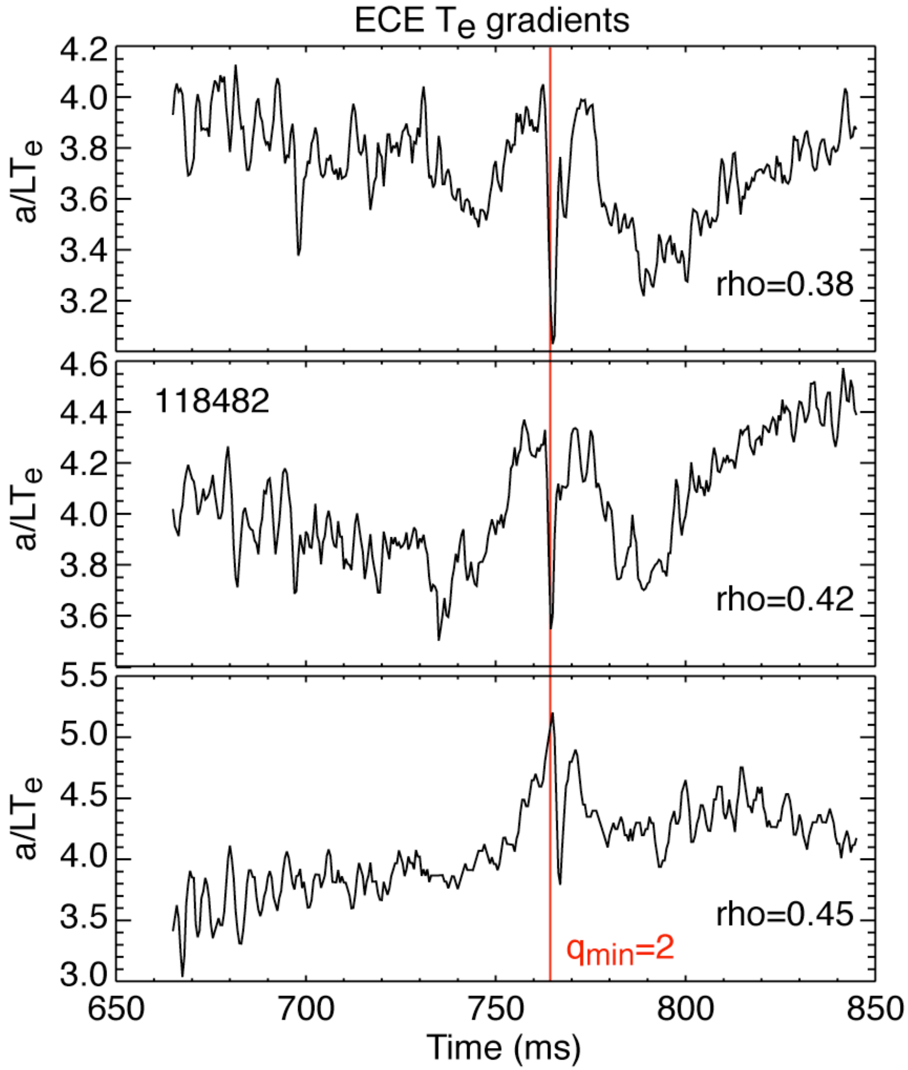
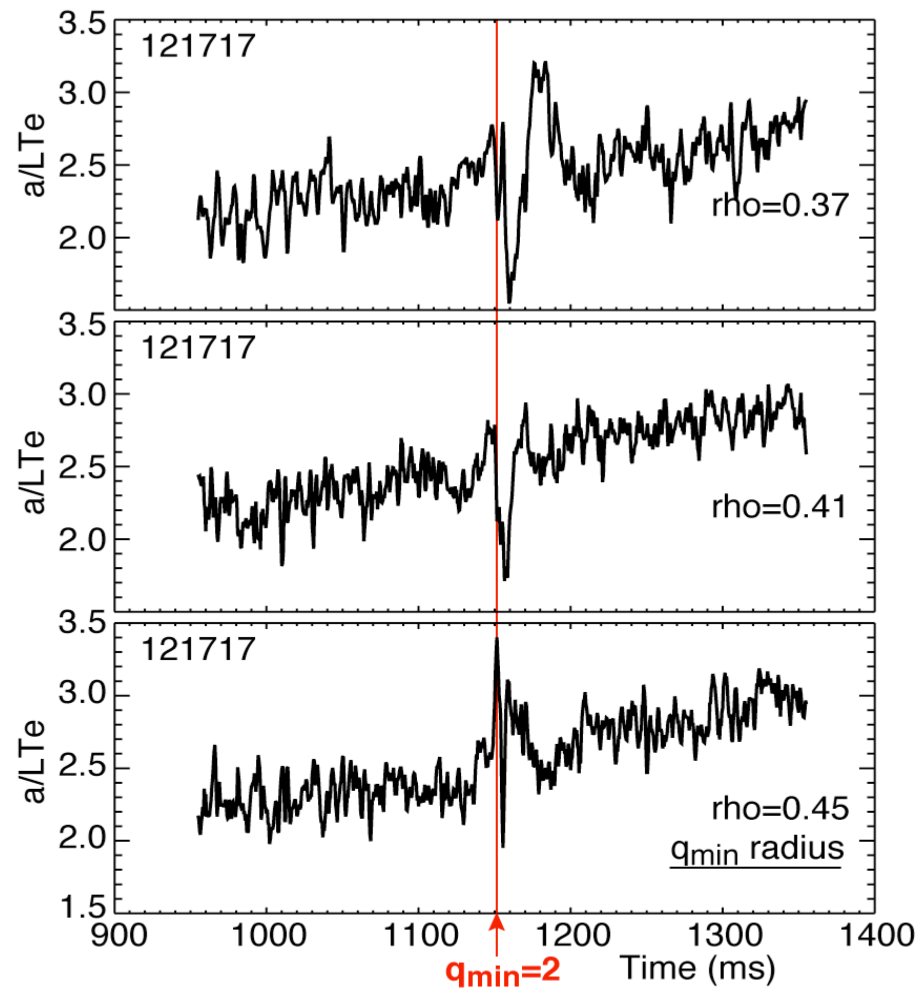
T_e gradient steepens before and after q_{min}=2, dips at q_{min}=2

- T_e gradients derived from adjacent ECE channels
- Changes shown are near and just inside radius of q_{min}, rho ~ 0.45
- Further evidence of transport changes preceding q_{min}=2



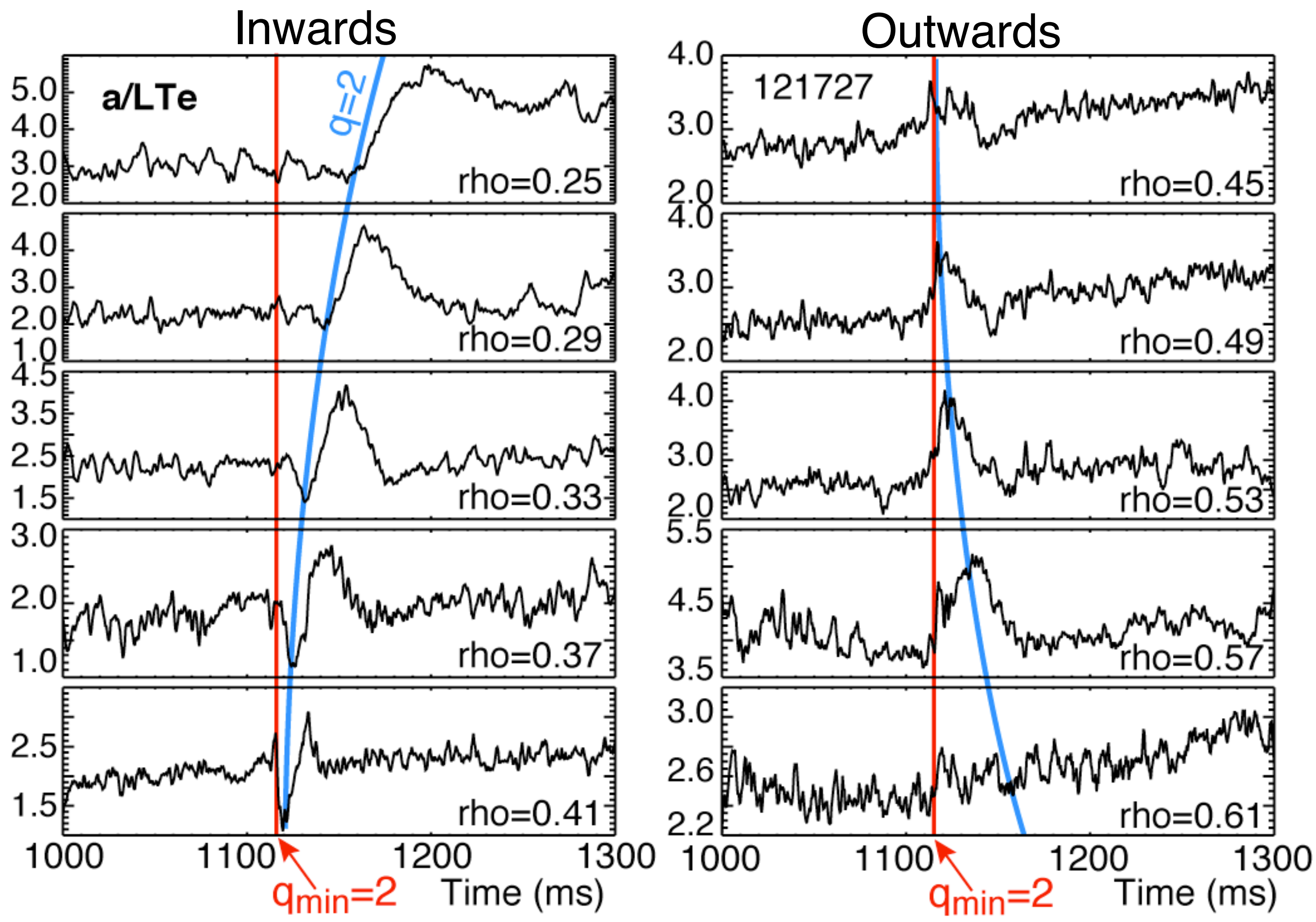
T_e gradient changes are similar for 5 MW case

- Interval for temperature rise preceding q_{min}=2 is often shorter, as small as 5 ms
- T_e gradient measurements underscore the locally transient nature of transport changes



Confinement changes propagate in with q=2 surface

- Structures in ∇T_e follow q=2 in time



Transport physics near low order rational q =m/n surfaces key

- DIII-D has transient Te-gradient, poloidal velocity, and high-n turbulence strongest near q_min = 2/1 where shear is very small
- Given smooth equilibrium profiles, the time and flux-surface averaged (equilibrium) profiles produced in GYRO simulations have large profile corrugations in the Te(r),Ti(r),n(r),phi(r) gradients profiles tied to low order rational surfaces
- These corrugations correspond to the various components of the time and flux surfaces averaged n=0 zonal flows on top of to the given smooth equilibrium
- GYRO is a global gyrokinetic code containing the "full physics" required to realistically and accurately simulate all steady state transport flows from given smooth equilibrium experimental profiles:

-ITG mode physics
-trapped & passing electrons
-collisions
-finite-beta
-real geometry
-equilibrium ExB & u_par shear
-finite rho-star

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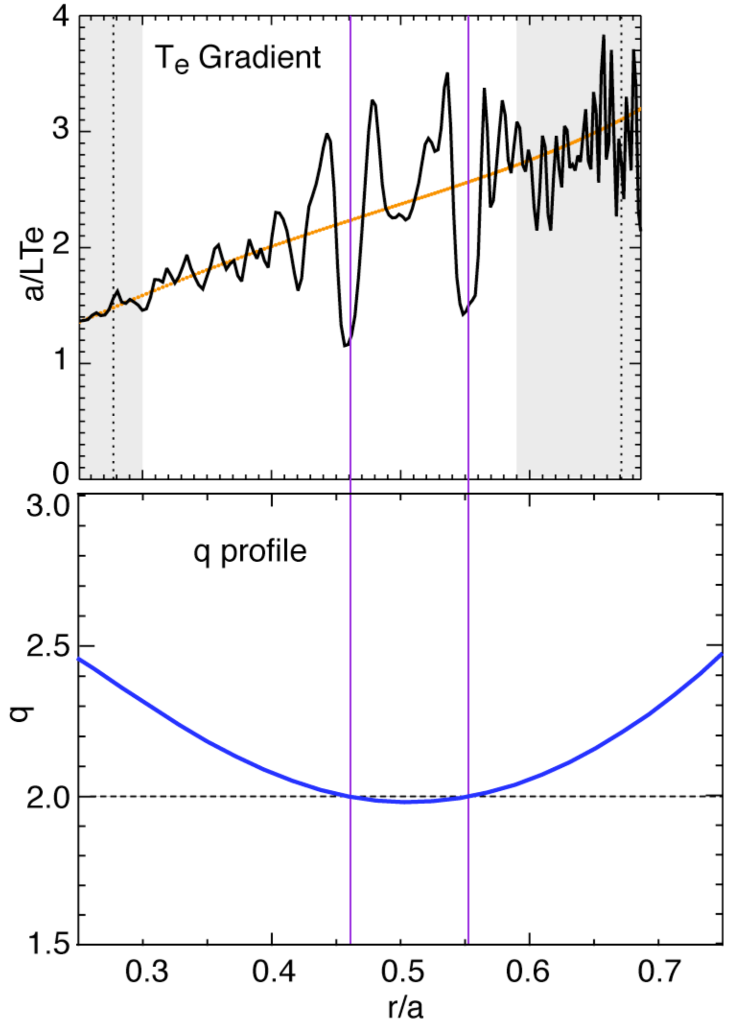
GYRO runs show corrugations in grad_Te/Te at low order rational q values near a qmin

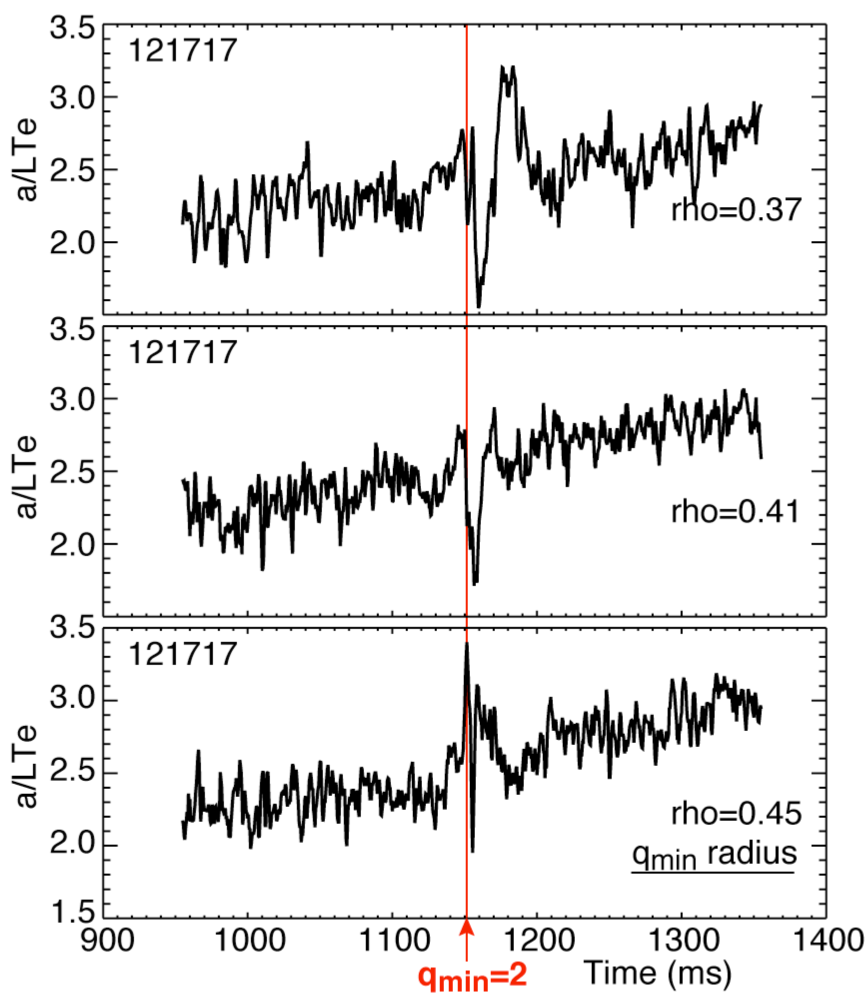
- The -grad(Te)/Te corrugations near vanishing shear, i.e. at q_min, are larger than for monotonic q profiles

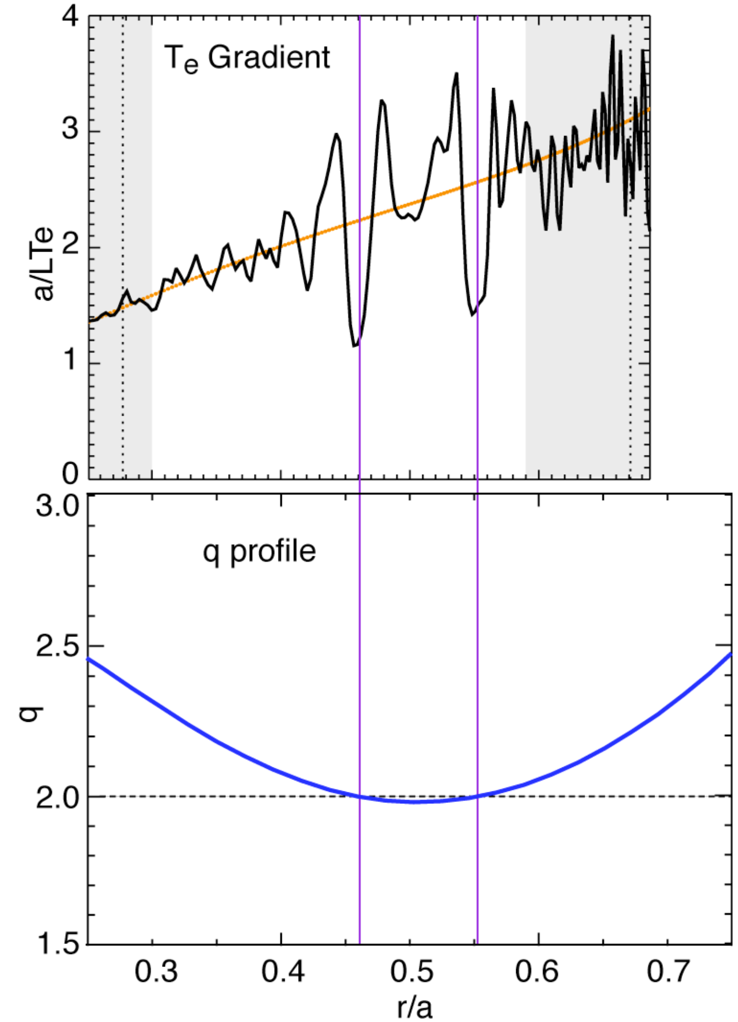
- This run: time average after nonlinear saturation from a given snap shot q_min = 1.98 profile

- The well-justified assumption is that the GYRO corrugations will follow the inner and outer q=2/1 surfaces as they slowly drift inward and outward



GYRO corrugations in radius should track the experimental time traces



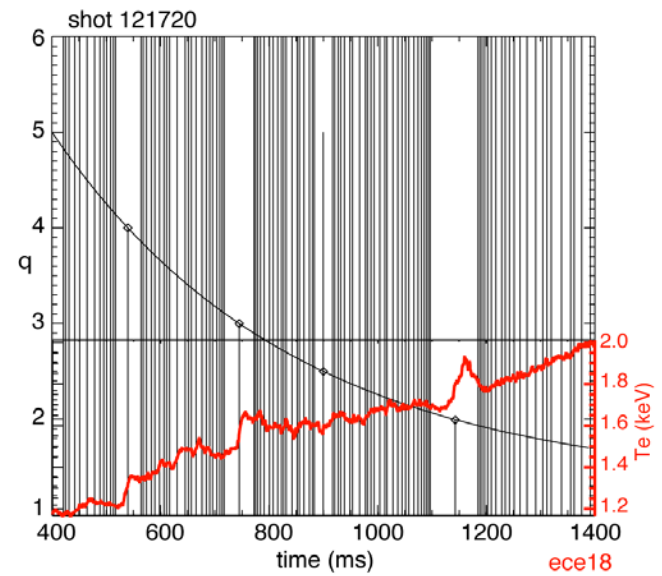


Corrugations related to density of rational surfaces

• Many devices have seen transport changes correlated with low order rational q values – tokamaks, stellarators

• The flattened Te-corrugations and enhanced ExB shear rates (not shown) result from low density of rational surfaces and results in slightly reduced flow at the low order surfaces

• Electrostatic GYRO reruns show nearly same level of corrugations ....hence "islands not important"

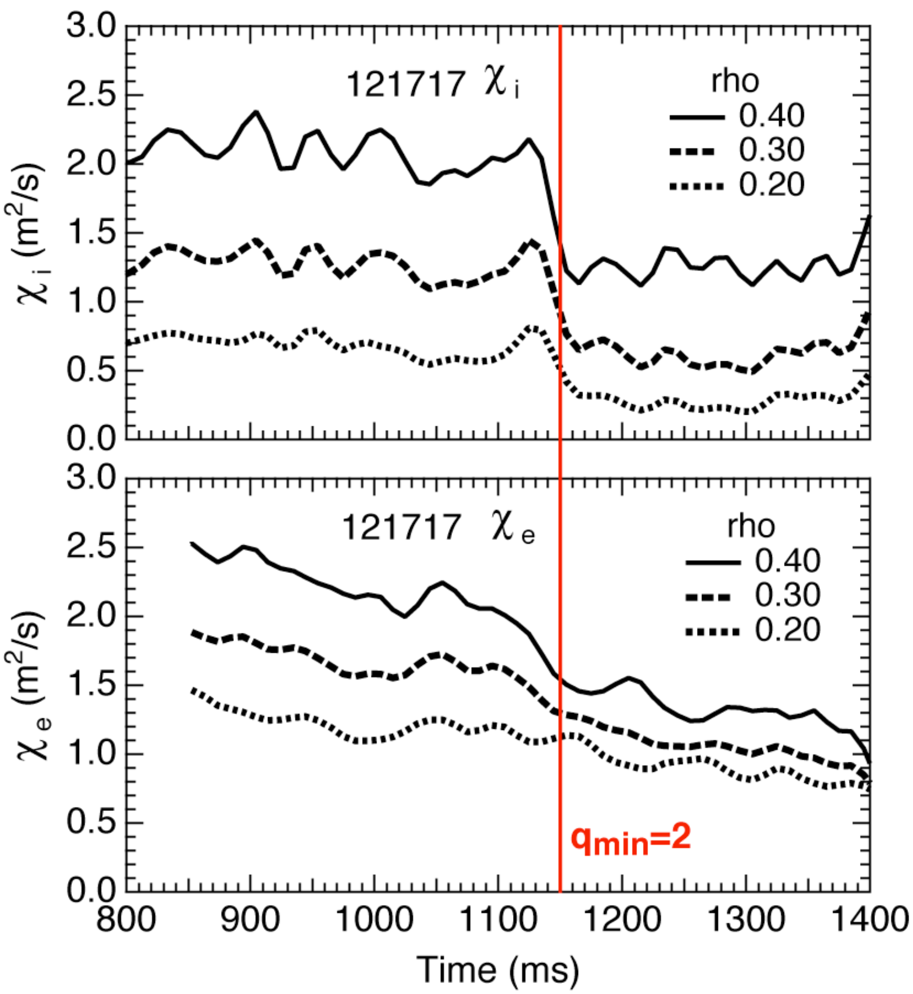


Profile corrugations, zonal flows, and tranport at low order rational q

- Zonal flows are low (near zero) frequency, poloidally and toroidally symetric electrostatic potential structures which vary only in radius on a small scale. They have time averages which are distinguished from the "smooth" background equilibrium only by their small scale
  - n=0 zonal flows are nonlinearly driven by high-n micro-turbulence modes
  - The ExB shearing in the n=0 zonal flows nonlinearly saturate and regulate the high-n modes
- The transport flow carried by the high-n micro-modes is localized about many m/n surfaces
- The divergence of the transport flow driving the zonal flows is strongly corrugated where the density of rational q surfaces is low resulting in a time averaging flattening of the Te (and Ti,n,phi) profiles at the low-order surfaces

χ_i drops at q_{min}=2 and remains low

- TRANSPP runs confirm improvement in ion confinement
- χ_e shows slow improvement, proportional to current soak-in, but no step changes
- Short time scale transport changes not expected to show up in TRANSP analysis



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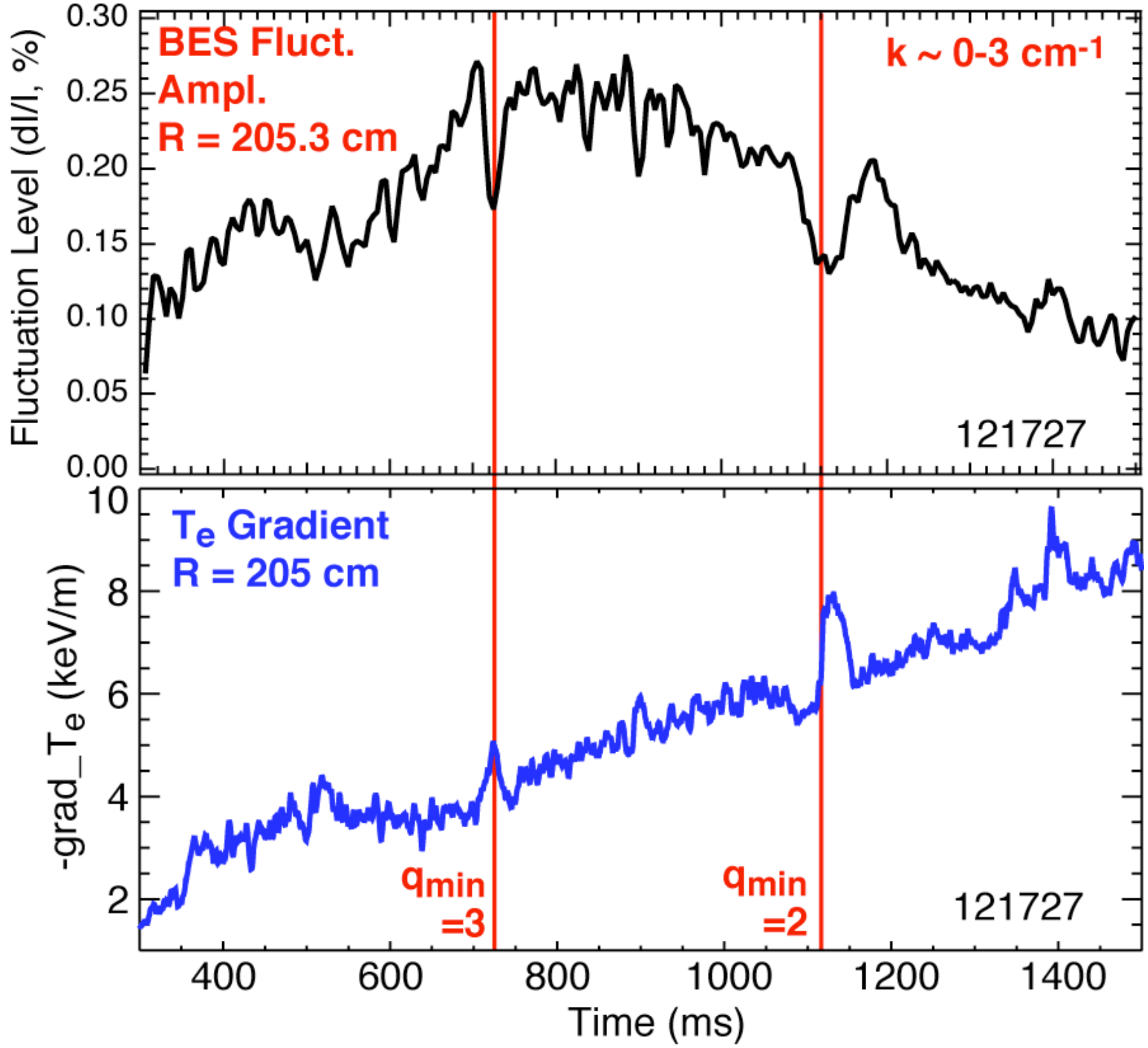
Decrease in density fluctuations coincides with local drop in χ_e near integer q_{min}

- Dip in fluctuations is localized to q_{min} radius



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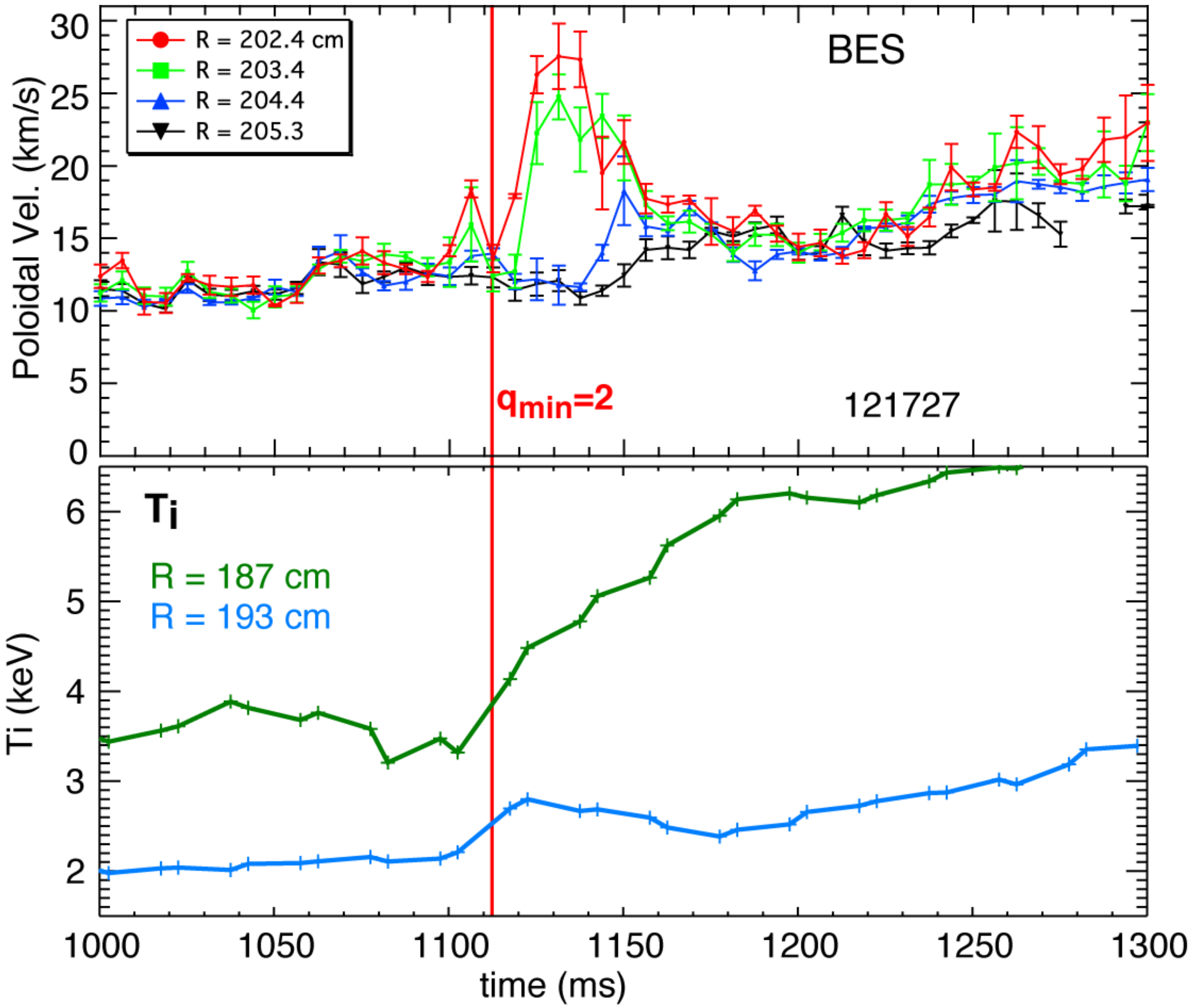
Localized jump in poloidal velocity occurs at q_{min}=2 trigger event

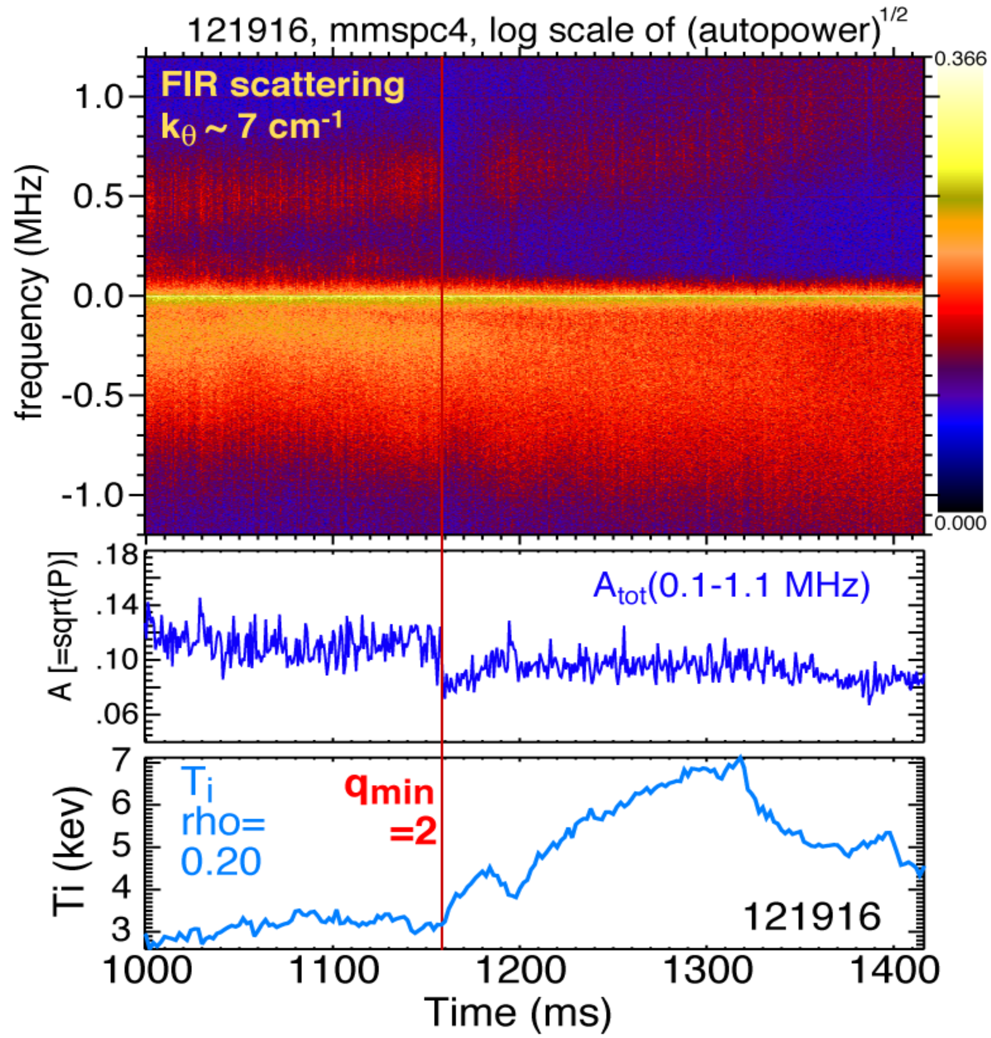
- Observed radial variation of velocity represents very large shear
- BES measurement near R_{qmin}

M.W. Shafer
QP1.00022
Thurs. AM



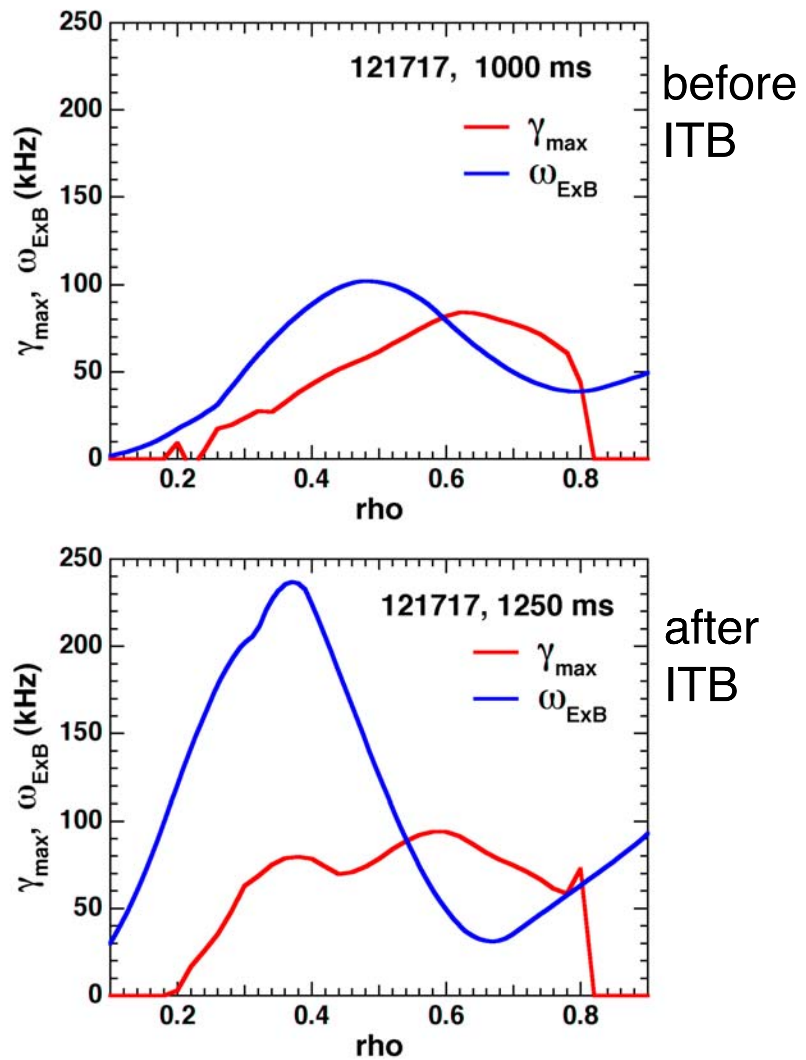
Drop in intermediate-k fluctuations starts at time of q_{min}=2

- Both transient and long term changes are seen in intermediate k data
- The persistent reduction is consistent with steady state core barrier



Core ion confinement follows standard ExB shear suppression of turbulence

- Before transition, shearing rate is insufficient for ITG suppression
- $\omega_{ExB} \sim \gamma_{max}$ to suppress ITG
- Event near q_{min}=2 pushes plasma into improved core confinement regime



Conclusions

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