1. EF scalings in H mode

2. 2/1 NTM stability and EF sensitivity vs q profile

Proposals for Tearing Stability Studies on NSTX in 2010

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with Stefan Gerhardt[2], Rob La Haye[1], Jong-Kyu Park[2], Steve Sabbagh[3] and possible Holger Reimerdes!

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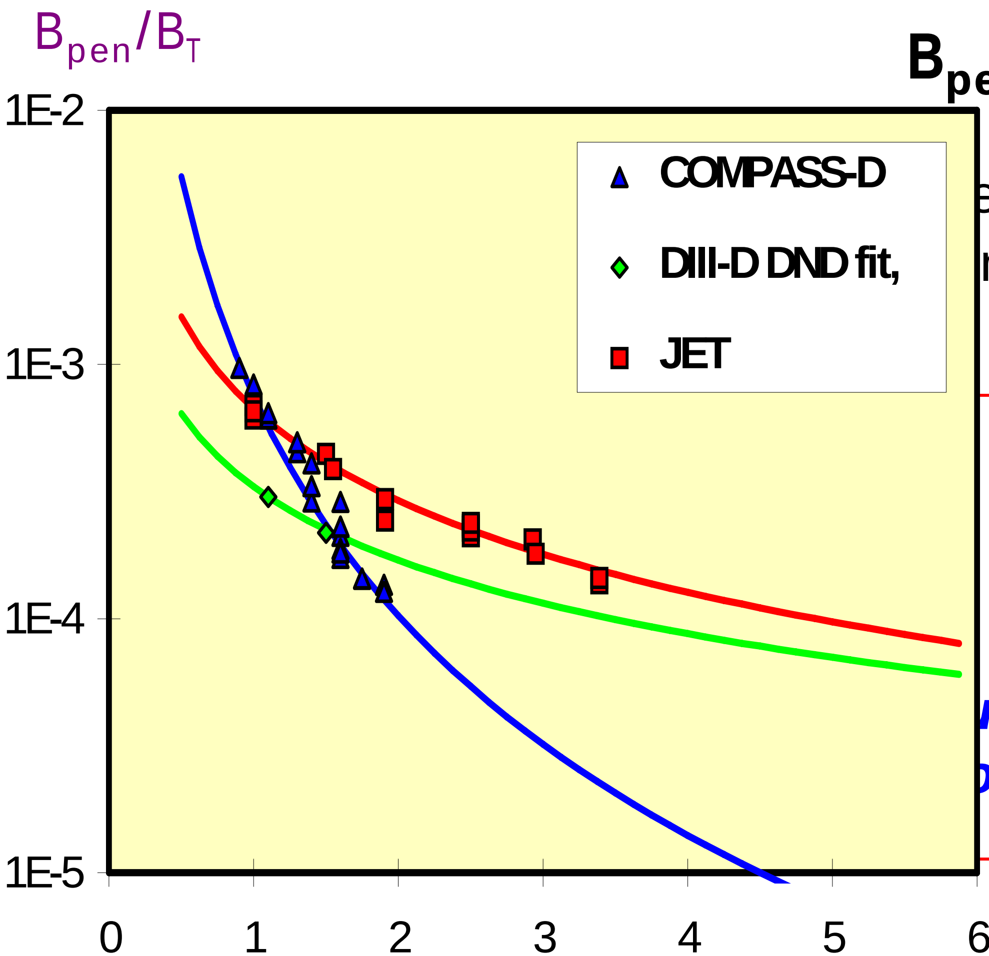
ITER's Error Field Scalings Deduced for *Ohmic* Plasmas
– *regime of concern at the time (low ne before H mode)*



- Scale using power law form:

$$B_{pen} / B_T \propto n^{\alpha_n} R^{\alpha_R} B^{\alpha_B} q^{\alpha_q}$$

educe $\alpha_R = 2\alpha_n + 1.25\alpha_B$ from
mensional considerations,

- *in line with approach for confinement scaling*

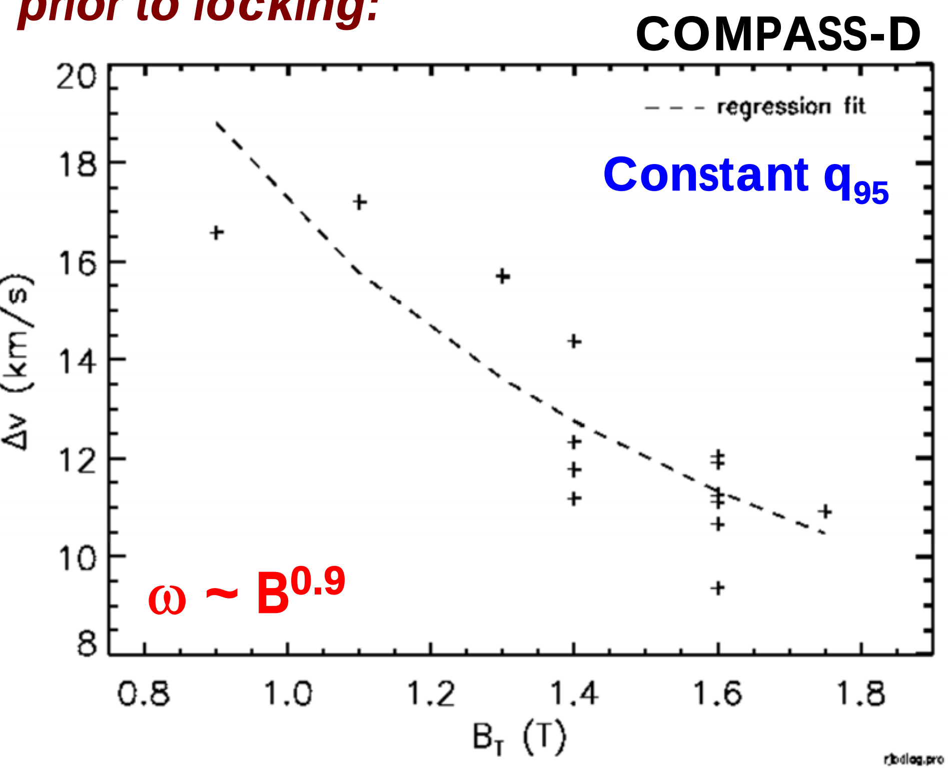
(Connor and Taylor NF 17 1047)

ut COMPASS-D behaves differently
om other devices

- ***Rotation behavior was different!***

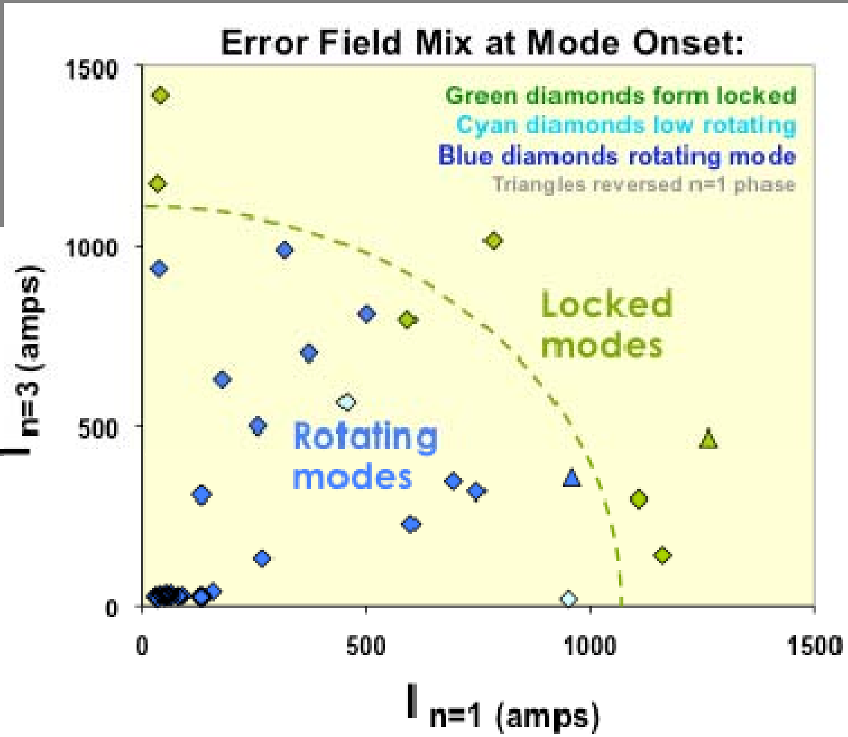
COMPASS-D had much stronger rotation scaling with BT than other devices *– likely due to rotation behavior*

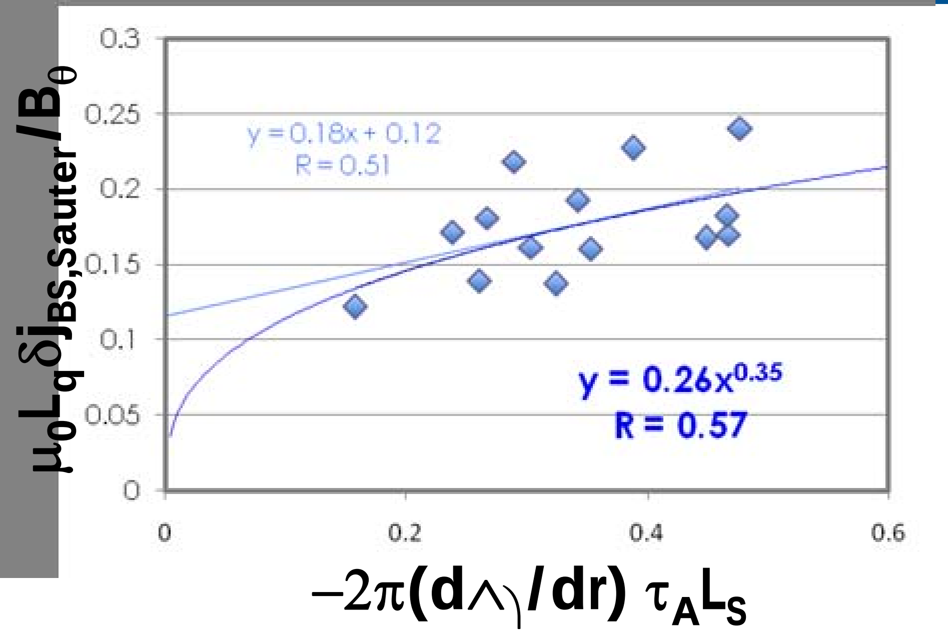
Boron III rotation change prior to locking:



- **Error field threshold when EF overcomes plasma rotation**
  - EF scaling implicitly folds in rotation variation with Bt, ne
- **Will plasma rotation in NBI heated H mode scale same as self generated rotation in Ohmic plasmas?**
  - ***No!*** (unless you're lucky)
- **Need new experiment to determine how EF thresholds scale in H-modes!**

- **Rotating mode accessed at lower bootstrap drive with less rotation shear →**

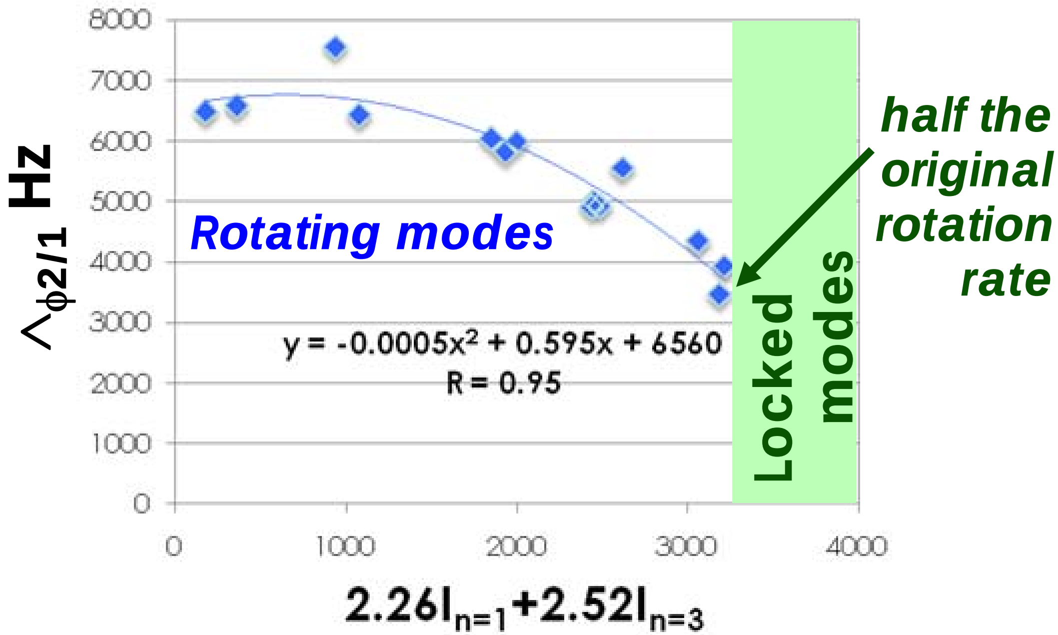




- **But can get two types of mode**
  - **Locked** or **rotating**
  - ***What is practical limit given these apparently different processes?***

In H modes, error fields can also destabilizing rotating modes – but does this matter?

- **Error field brakes plasma:**
  - If close to 2/1 NTM beta limit, the 2/1 NTM can is destabilised by the reduction in rotation shear
  - Further from NTM limit rotation braking reaches bifurcation point for ‘penetration’ – bifurcation to large locked mode



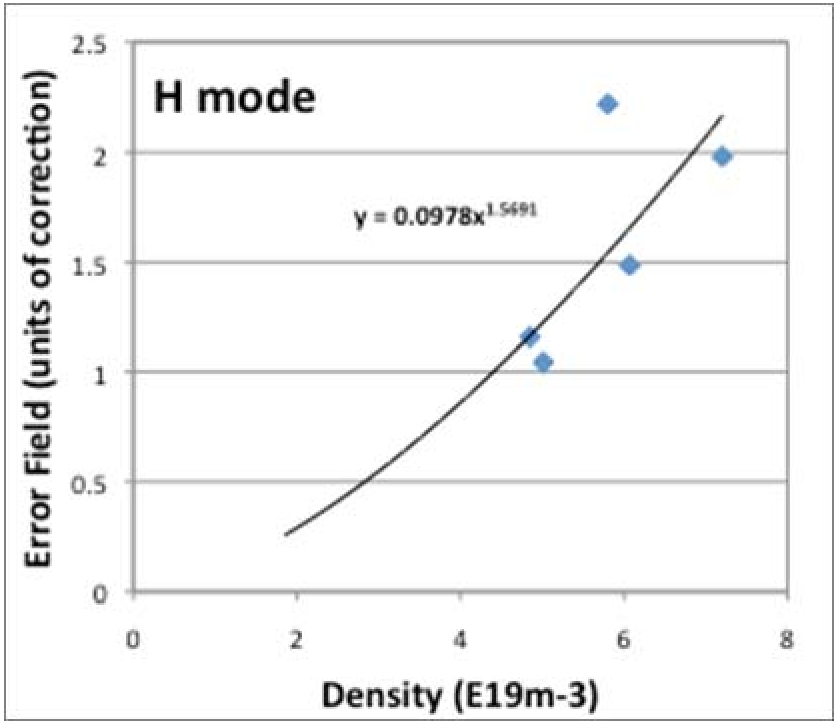
- **Key point is mode forms at lower beta/bootstrap when substantial rotation braking happens**
  - ***Criteria is about overcoming plasma rotation to reach high braking regime***
  - A lot like Ohmic criterion

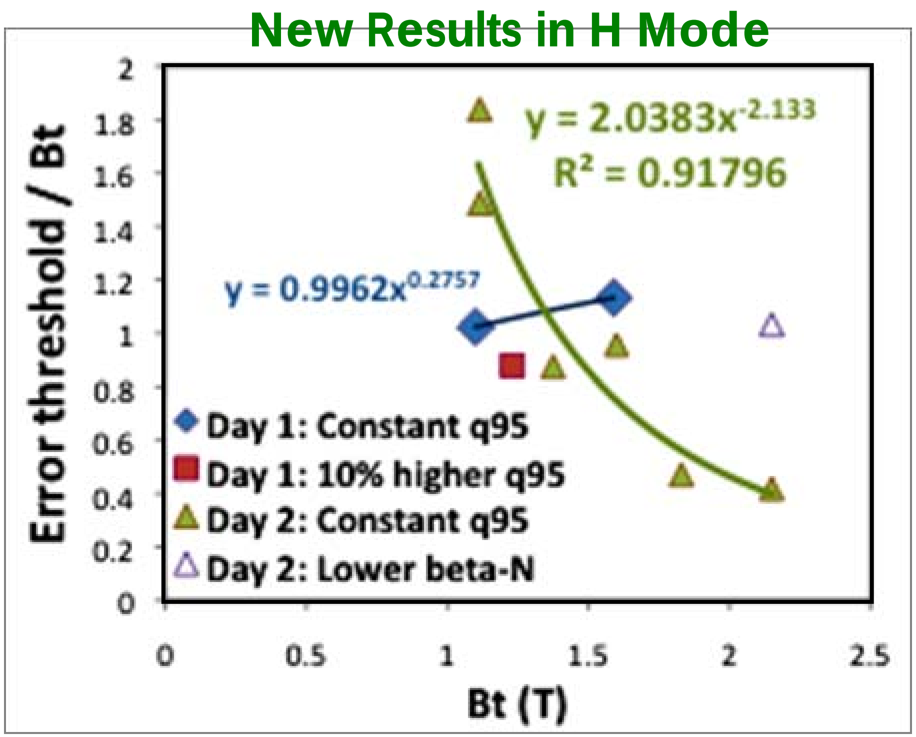
Governing Physics – á la old Ohmic theory…
Penetration is about overcoming the plasma rotation

- **Modes form when resonant surface is braked by resonant response to EF to half it's natural frequency**
  - Tiny static island induced by EF
  - Viscous forces try to keep bulk plasma rotating slipping past the island - *this opposes island growth*
  - Torque exerted through island and viscosity to brakes plasma
    - *N=3 NTV effects assist this process?*
  - If rotation slows enough, island can grow, increasing torque and bifurcating to a locked mode state
  - Threshold scales as $B_{pen} \sim B_T\, \omega_0\, \tau_A\, (\tau_{rec} / \tau_v)^{1/2}$
    - *ω_0 often taken to be electron diamagnetic rotation*
- **Criteria could also be regarded/generalised as condition for when we approach rapid rotation change**
- **Critical elements are:** what determines ω_0; whether plasma response changes; and how readily plasma rotation is overcome

DIII-D just identified likely strong scalings with n_e and B_T
Need to confirm & want extrapolations for ST

- **H mode density scaling steeper than Ohmic - favorable**





- **But toroidal field scaling much worse**
  - And absolute levels of field required are modest (~1-2G)
  - ***Raises concern & needs investigation elsewhere***

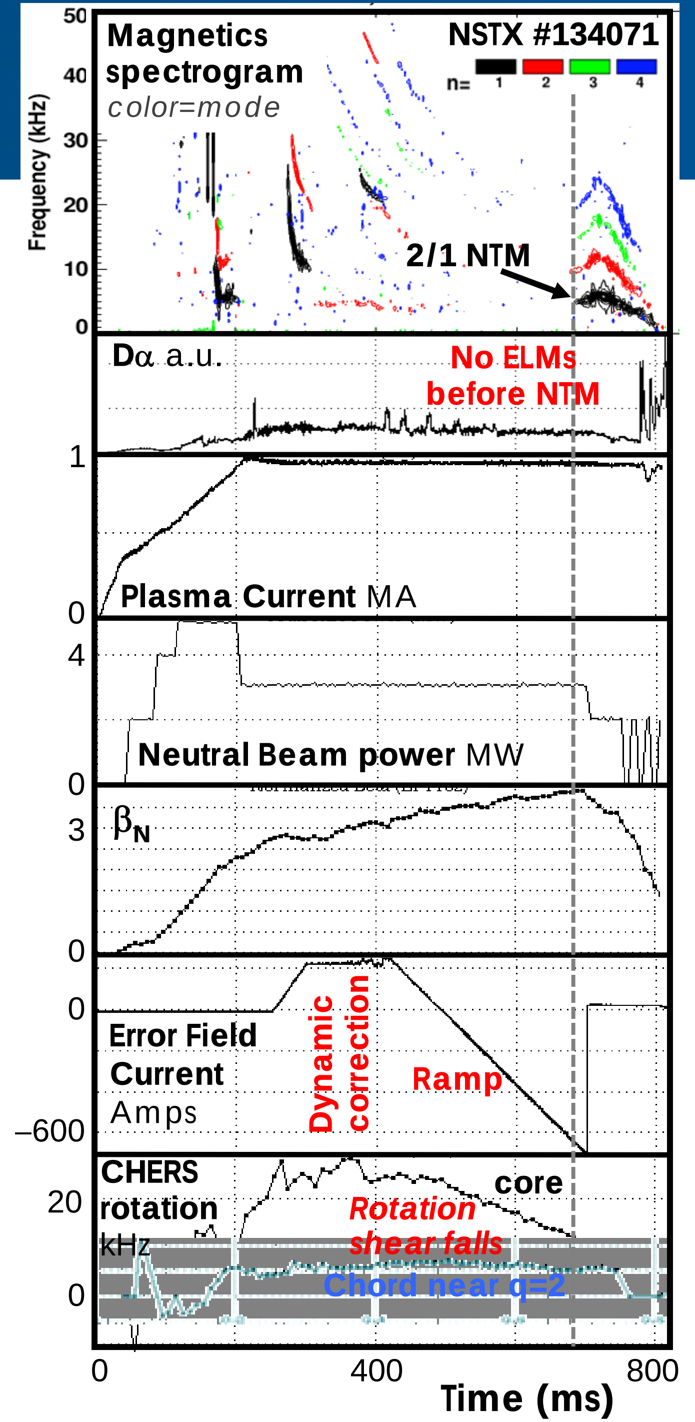
Experiments Are Needed to Extrapolate EF Threhsolds to Next Step Devices – like ST-CTF or ITER

- **Ramp up error field to measure mode thresholds**
- **Scan in ne and Bt**
  - Infer machine size scaling from Connor-Taylor constraint
- **Hard part:**
  - Maintain constant shape, betan, li and q profile at time of mode onset ***– can we do this?***
  - Also what to do with rotation? (Natural beam drive, or n=3 braking to control to given M_A)

- ***These experiments are essential if you want to understand how the torque balance based error field threshold extrapolates to future devices.***

Proposed approach

- **Build on successful shot developed in 2009**
  - Scan in Bt(~Ip) and density
  - Li to control ELMs & conditions
  - Adjust NBI start time if qmin (MHD) trajectory varies
  - Ramp EF to mode… but:
    - β_N is time varying: Adjust EF ramp to get mode strike at similar β_N
- **Uncertainties are rotation variations** (strip out from other scans) **and more profound profile changes**



Shot Plan – counting good shots

1. **Establish reference and tune if needed – 3 shots**
2. **Change density (ideally: puff gas after 300ms to avoid big profile effect) – 3 shots**
   - If needed tune heat switch on time
   - Tune EF ramp rate/time to get mode at same betan
3. **Repeats at different densities, anticipating adjustments based on item 2 observations: 3 more points - 6 shots**
4. **Change to lower toroidal (Ip in proportion) – 3 shots**
   - Repeating above – reoptimisation as in step 2.
5. **Change to higher toroidal field – 2 shots**

Questions

- **Is profile compensation approach good enough (adjust NBI on time to get similar qmin)?**
- **Best way to handle rotation for scaling?**
  - Live with whatever rotation we get from co beams (presumes a correction would be needed for future device – but leaves scope of this to an other study – JKP?)
    - This is reasonable – like Ohmic we just regard rotation as a hidden variable, implicit in process but determined by other parameters
  - Fix NB levels for fixed torque
  - Fix rotation with n=3 fields (too difficult I think for this 1st cut & raises issues of validity, as n=3 fields help access mode!)
- **Impact of 2010 plasma conditions/machine changes?**
- **Intershot MSE qmin possible?**

2^{nd} proposal

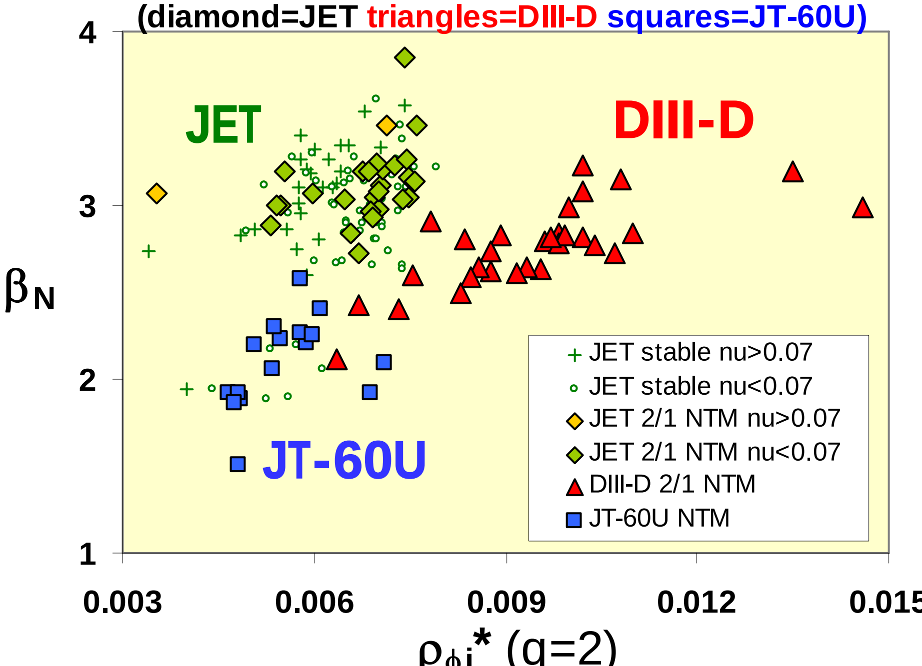
Role of q profile in 2/1 NTM stability

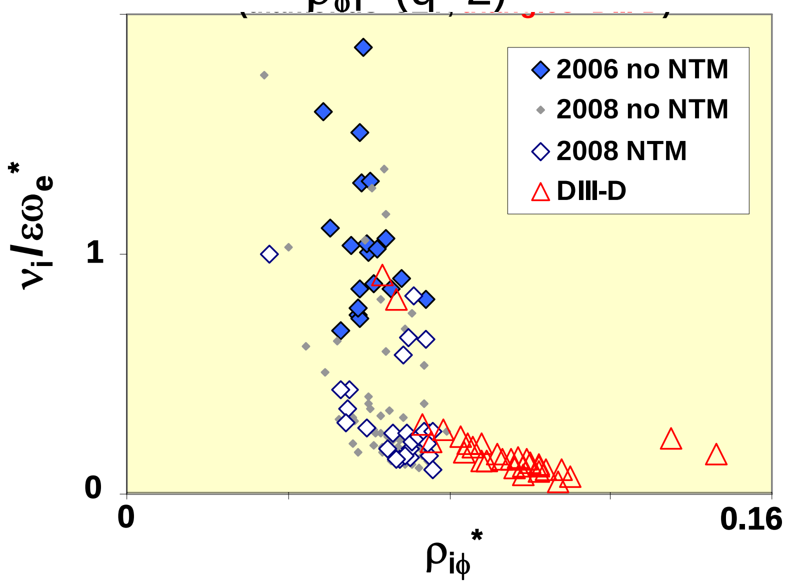
JET Hybrid Plasma Sit Above β Limit of Other Devices: *Other parameters coming into play – q profile?*

- **JET sits above DIII-D and JT-60U trends**
  - JT-60U lower rotation →lower β_N
  - But DIII-D high rotation

- **Possible collisionality role? <u>No</u>:**
  - JET unstable at ◆low ν^*
  - But stable at +high and ∘low ν^*

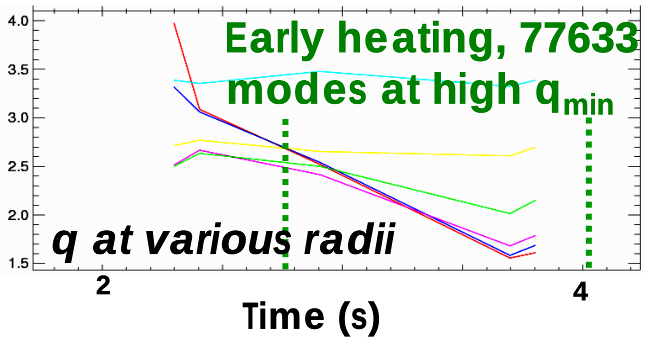
→**Collisionality provides 'access condition' for NTM**
  - Enables q profile modification
  - Can change Δ'
  - ***q profile is the parameter to test…***



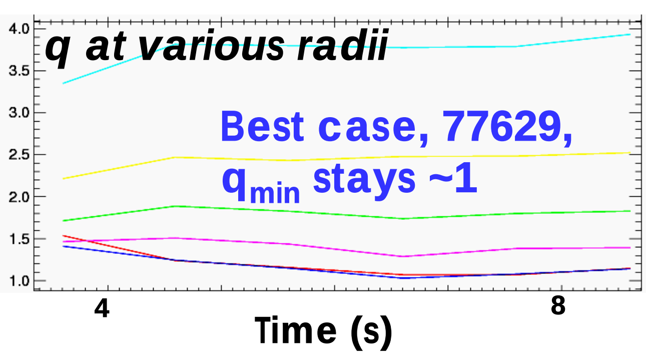


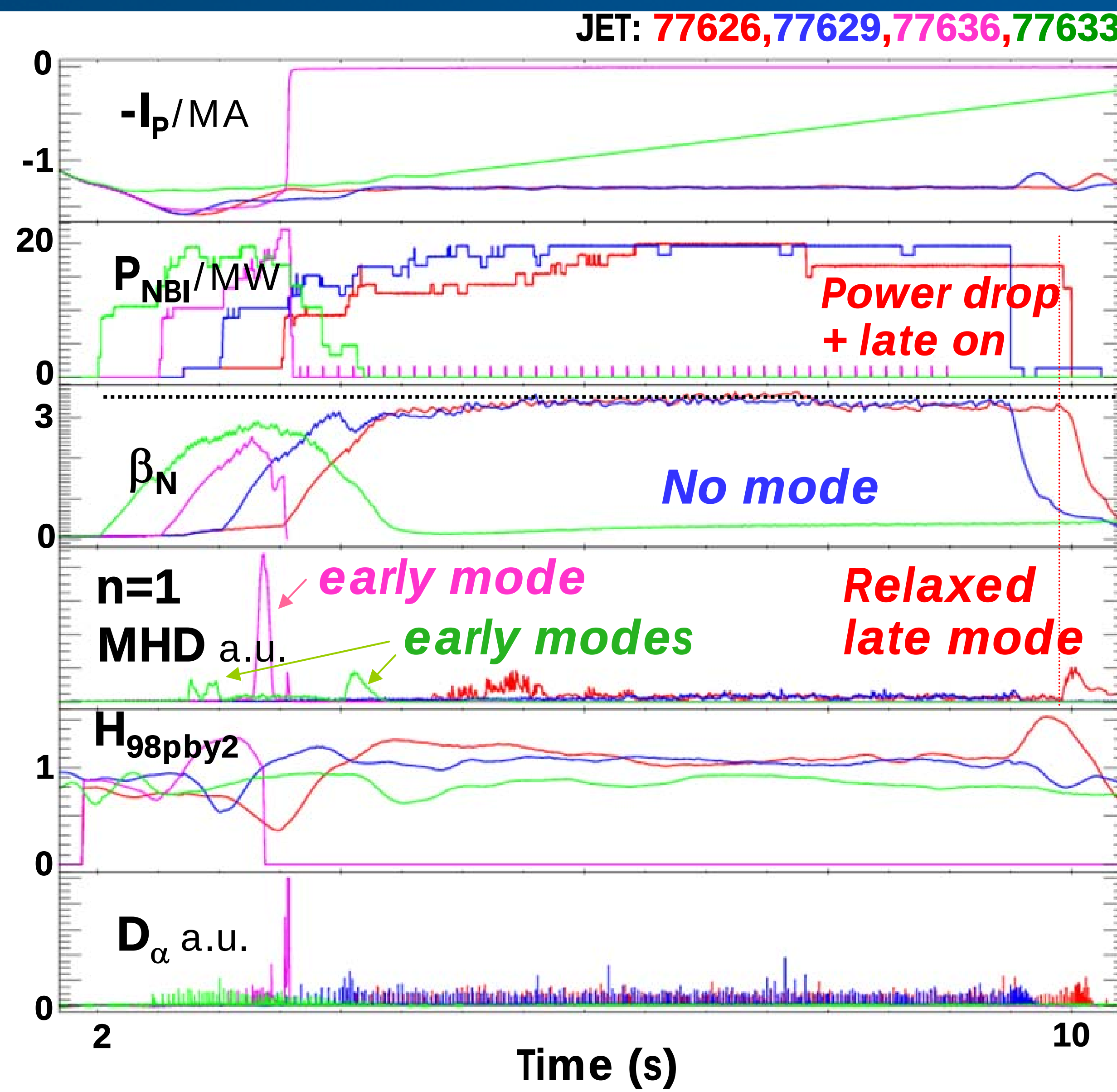
Heating timing scan shows 'just right' degree of relaxation needed

- **Mode if profiles too 'advanced':**



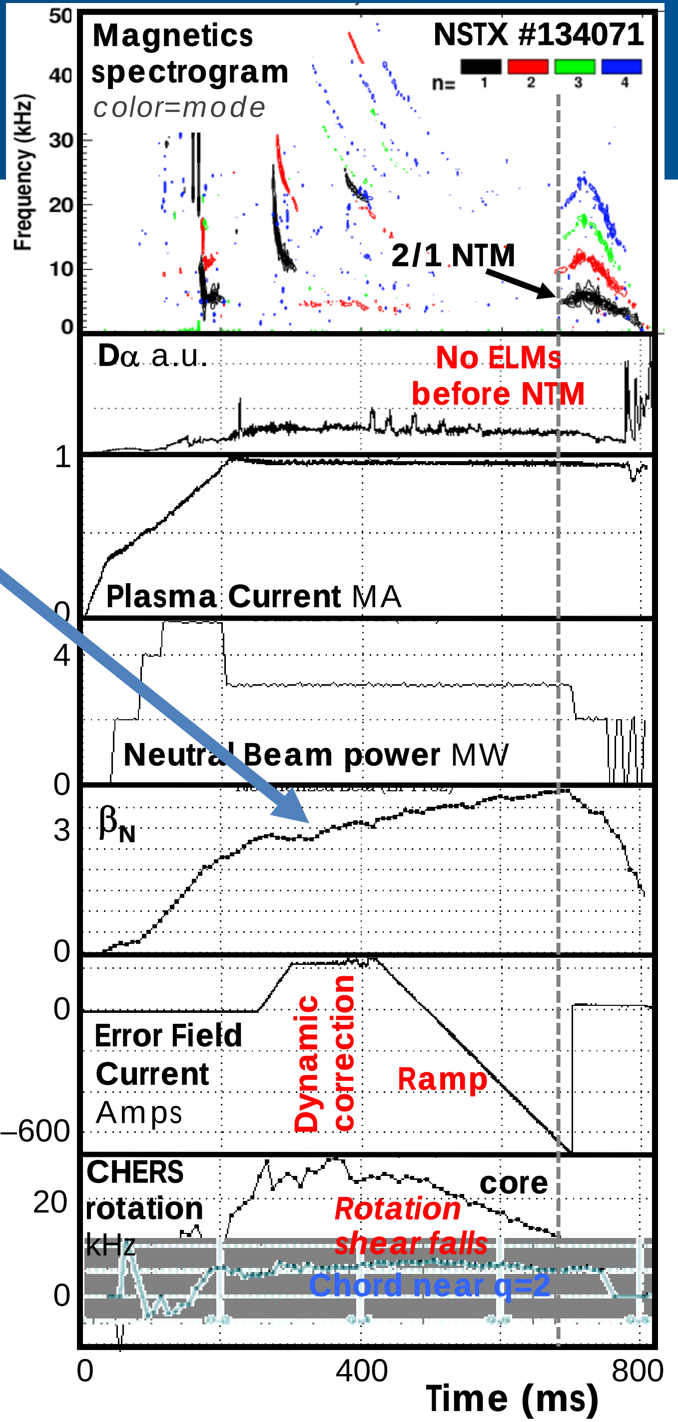
- **Fully relaxed plasma also less stable**
  - Mode at lower β_N or occurs later

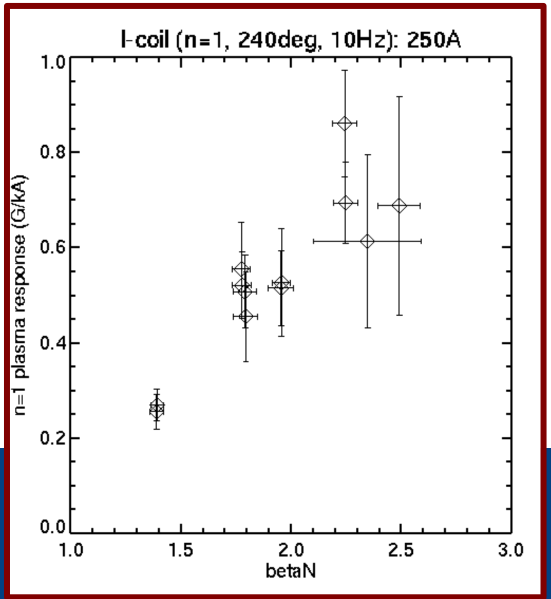




NSTX an ideal place to explore q profile role in detail

- **Plasma naturally relaxes vs time**
- **Can ramp beta to excite mode**
  - Scan NBI timing & power to vary $\mathbf{q_{min}}$ vs β_N trajectory
- **Repeats with EF applied**
  - to see if plasma response stronger as tearing mode β limit applied





DIII-D: Plasma response to error field increases with β_N:

- ***How does response change with Δ'?***

Detailed Considerations

- **Similar approach to last experiment, but here try to vary timing of NBI start to change q profile**
  - Most interested in qmin value – does approach to 1 have special role?
    - A fine scan of this would be very insightful
  - Trajectory approach is powerful – always get mode – just change what beta and qmin we get it at
    - by varying time and power to change beta ramp up rate
- **EF response is a novel element**
  - Looking for change with deltaprime (influenced by qmin) would be a first
    - Can we probe EF response readily – how best done on NSTX?

Shot Plan

  - ***More straightforward than EF study as profiles and beta onset of mode are allowed to vary***
- **Repeats of reference shot at different power levels and timings – 10-12 good shots desirable**
- **Repeats of favorite cases with EF response probed vs time as beta rises to limit – 5-6 shots**
  - Possible extension to look at error field threshold with ramp applied some pre-determined interval before natural mode
    - What interval?