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XP1027: RMPs below the ELM triggering threshold for impurity control

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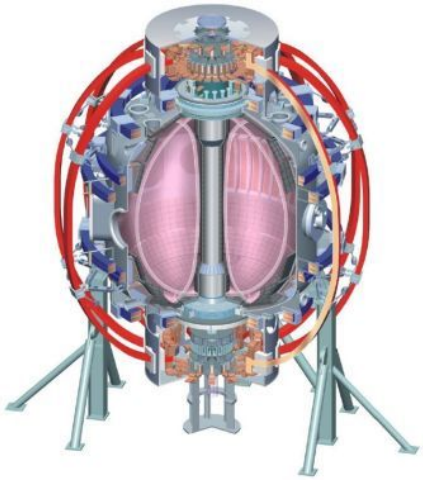
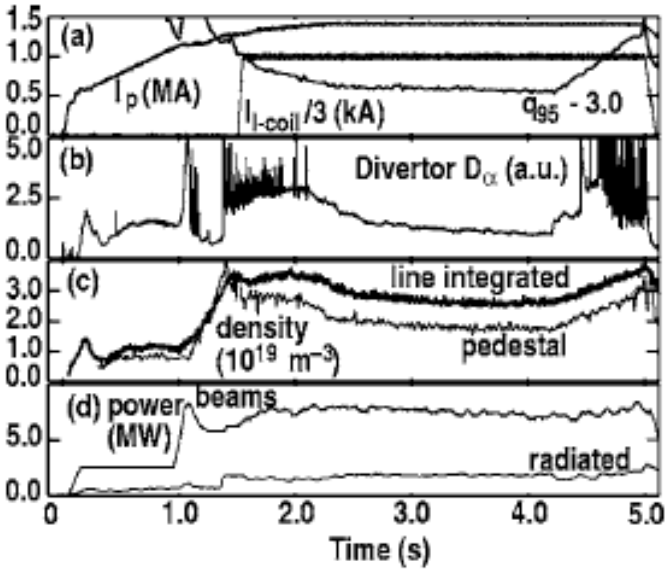
Team Review
March 10, 2010



Motivation: reducing impurities without large ELMs

- ITER support: impurity control in ELM-free/small ELM regimes
- Evidence from other experiments that 3D fields can reduce impurities (without ELMs)
  - DIII-D: increased particle transport during RMP ELM-suppression keeps radiated power down
  - Impurity screening on limiter tokamak ergodic divertor experiments (Tore Supra, TEXTOR)
  - Also seen on stellarators (LHD, W7-AS)
    - Attributed to large friction drag on impurities towards divertors
    - Happens at high density

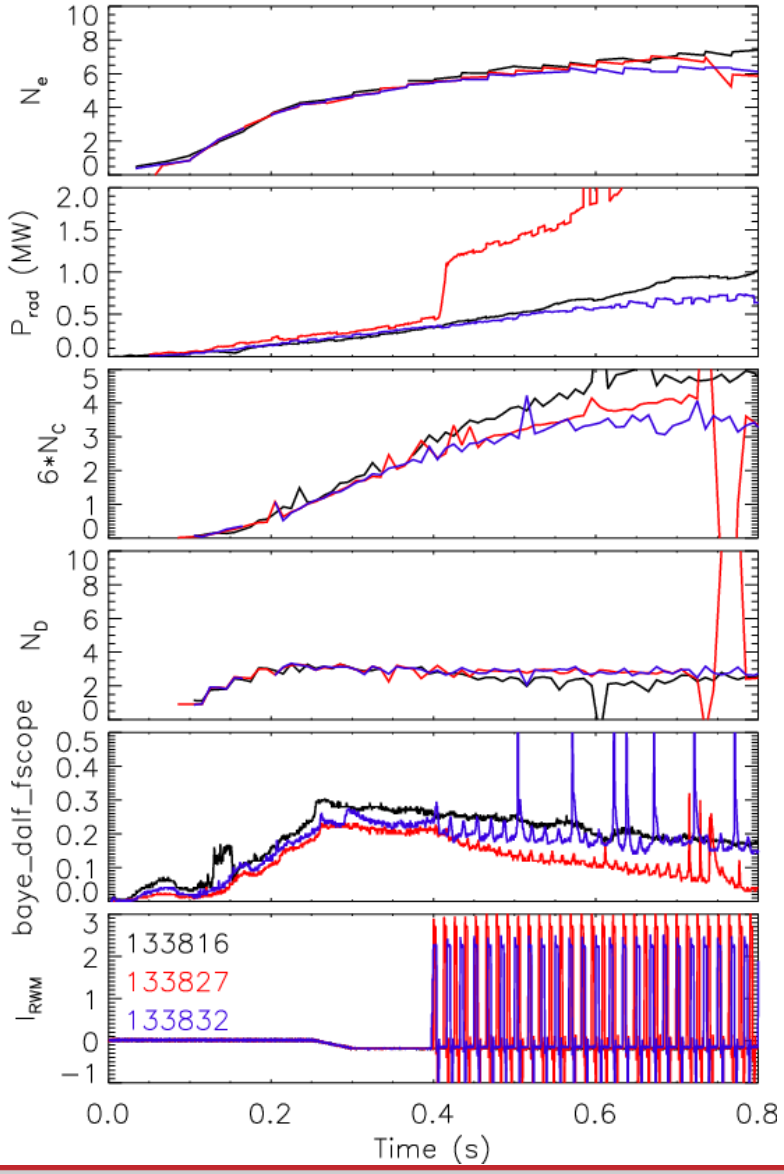


*Evans, PoP **13** (2006) 056121

Sub-threshold triggering pulses show hints of increased particle transport without large ELMs

- Shots from ELM pacing XP943
  - 3kA SPA pulses each 4ms in duration gave reliable triggering
- Two waveforms with unreliable triggering
  - Pulse duration reduced to 3ms: too short to trigger ELMs
  - SPA current reduced to 2.5 kA (4ms)

- D_α shows small increase during non-triggering pulses, implying increased particle transport
- Even without ELMs, carbon inventory is reduced from control
- Radiated power jumps at ~.4s in one case, but not the other (bad luck?)



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  - Pulse duration reduced to 3ms: too short to trigger ELMs
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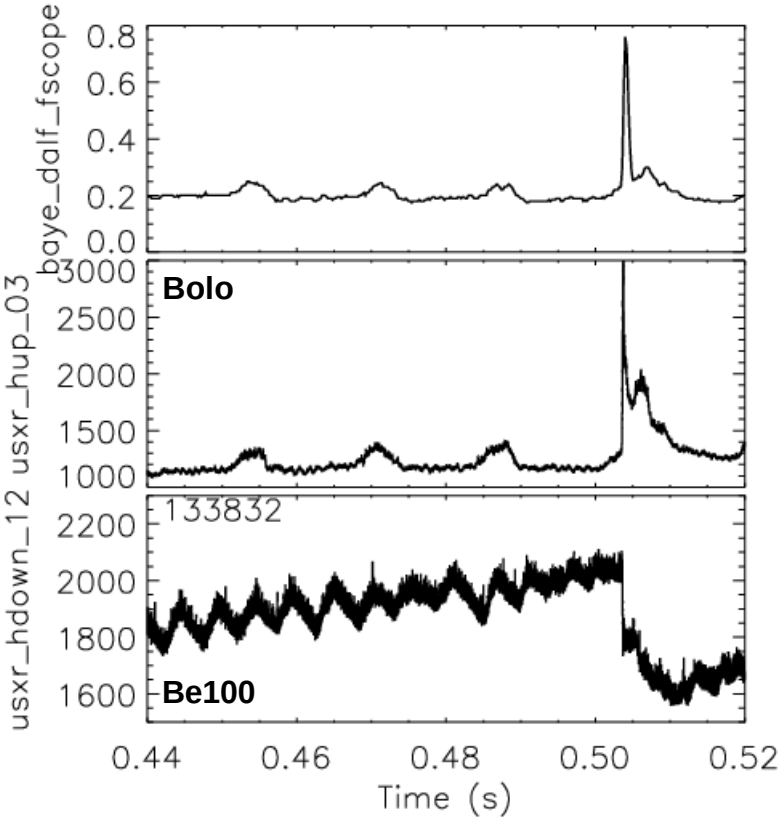
- USXR array in bolometry mode supports that non-triggering pulses affect particle/impurity transport
- Difference from normal large ELMs is evident in USXR signals
  - Magnitude of rise is ~10% of ELM
  - Much slower rise and fall on Bolo channel
  - ELM shows fast drop in Be100 filtered channel, in the noise during non-ELMs

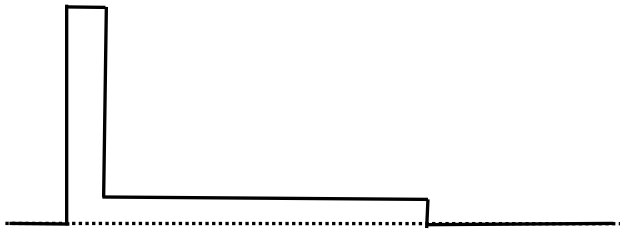


½ day plan: use n=3 fields strong enough to affect particle transport, not strong enough to make ELMs

- Create reference shot (2 shots)
  - Reload of 135182: 800 kA, 0.45T, κ~2.4 δ~0.7, P=4MW
  - Adjust lithium as necessary to be ELM-free (~250 mg/shot for 135182)
- Reproduce "stochastic response" using n=3 pulses (3)
  - Start with 2 kA, 8 ms, pulses at 50 Hz (from XP943, 4 ms @ 2.5 kA gave several non-triggering pulses with D_α response)
    - If no D_α response, restore 133827 SPA waveform (77 Hz, 3 kA, 3 ms)
    - If still nothing, move to reduced density reference (if available)
  - Adjust duration of pulses to avoid triggering ELMs
- Change amplitude of SPA pulses (3)
  - Pulses to 2.5 kA, 5 ms, 50 Hz
  - Again, adjust to avoid ELMs
  - Increase pulse frequency if duration is short enough

½ day plan: use n=3 fields strong enough to affect particle transport, not strong enough to make ELMs

- If non-triggering pulses have affected P_{rad}, N_C, Z_{eff} behavior, then adjust SPA pulses based on results so far: (6)
  - If higher amplitude/frequency is more promising for impurity control, increase SPA current to 3 kA shorten pulses, increase freq
  - Else reduce SPAs to 1.5 kA, increase duration, reduce freq
  - Repeat as time permits
- If impurities have not been affected, try new SPA waveform
  - New waveform: use strong initial 3D field to initiate stochastic response, then drop the field to low level to maintain it
  - Current of initial spike based on scan done so far



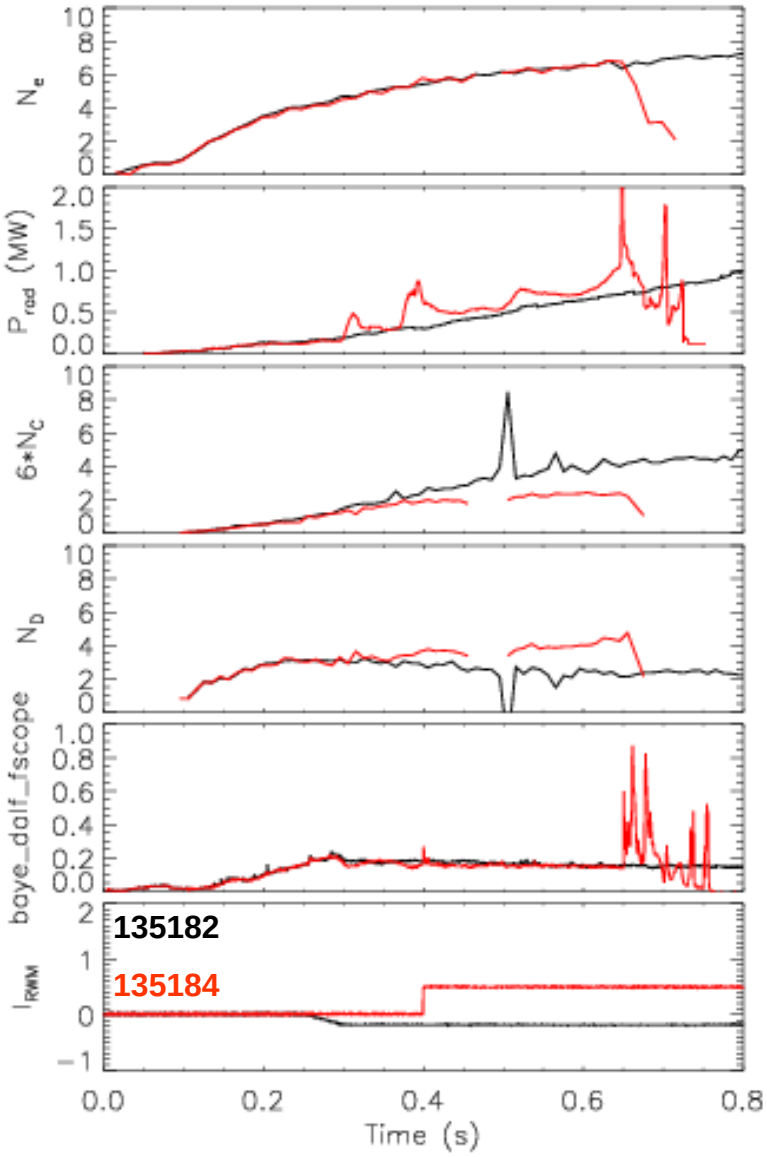
Operational requirements

- Required/desired machine capabilities
  - LITER is needed, with high enough evaporation rate to fully suppress ELMs
  - RWM coil set and SPAs, configured as n=3 (keeping in mind tolerable amplitude and frequency of pulses)

- Diagnostics
  - Profile diagnostics: MPTS, CHERS
  - Impurities: boloms, VB needed, X-ray spec would be nice
  - Edge diagnostics: ERD, reflectometers, FireTIP, GPI, Reciprocating probe, Phantom cams, USXR, fast IR cam, D_α cam, filterscope, etc.

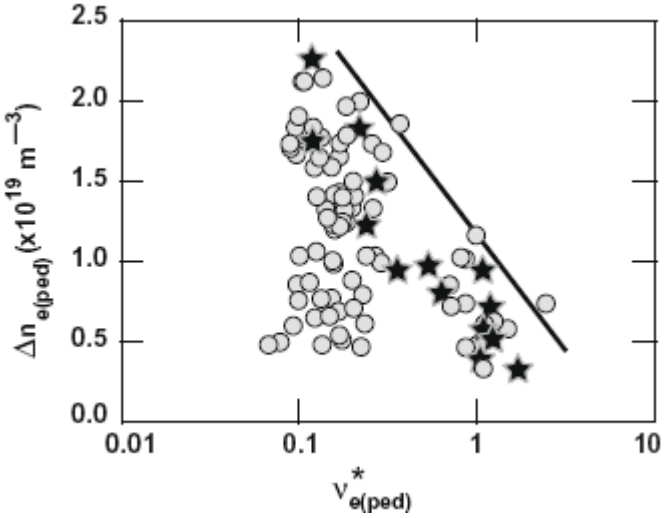
Some evidence exists for impurity reduction with 3D fields (but without ELMs) in NSTX

- From XP 926, SPA current scan to find threshold for ELM destabilization
  - Heavy lithium usage->ELM-free with significant impurity accumulation (black)
  - SPAs at 500 A, not enough to trigger ELMs (red)
- Electron inventory unaffected by 3D field, and radiated power has blurbs before SPAs that make behavior hard to interpret
- Carbon inventory is significantly (~30%) less in shot with 3D field



Effect of 3D fields may be stronger at low collisionality

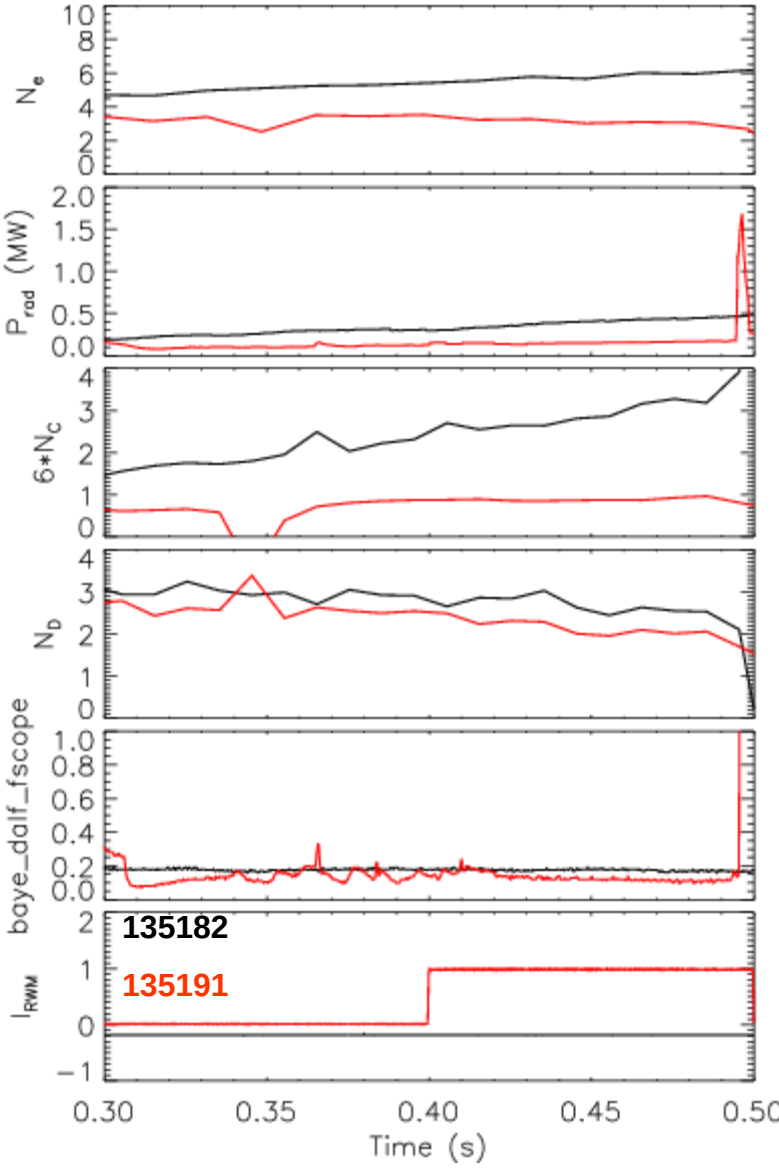
- DIII-D sees maximum pumpout at low collisionality



DIII-D density pumpout during RMP ELM suppression:

Unterberg, JNM ***390-391*** *(2009) 486*

- One example from NSTX: shot after an aborted one (i.e., double lithium) ran through at low density
- 3D field turned on at 0.4s
  - No ELMs triggered
  - Electron inventory starts decreasing
  - Carbon inventory constant



Effect of 3D fields may be stronger at low collisionality

- Before n=3 field is applied, edge electron and carbon densities are reasonably constant or increasing in time
- After n=3 field is turned on, both start decreasing