NSTX

U.S. DEPARTMENT OF ENERGY | Office of Science

Advanced Scenarios and Control 2020 "mini" Results Review

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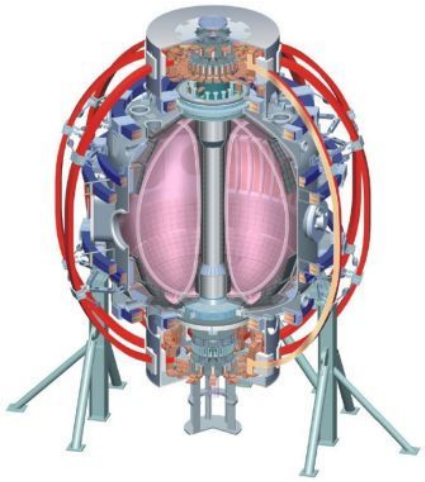
ASC TSG Leaders

Contributions from:
J.M. Canik, J.E. Menard

Sept. 30th, 2010



College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
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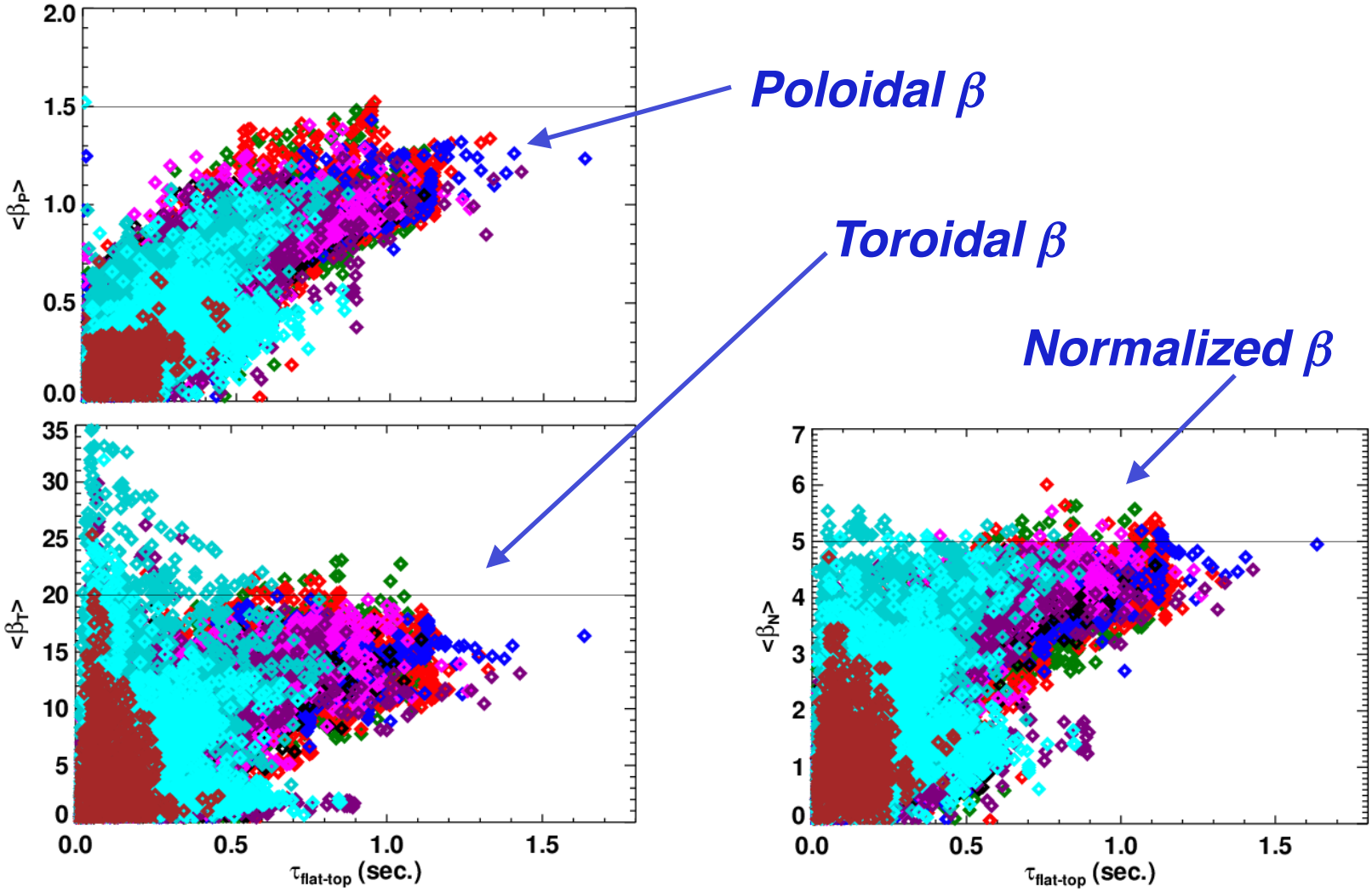
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

ASC Activities in 2010

- Developed the LLD target configuration
- Run 8 XPs.
  - XP-1003: X-point height and OSP control (Kolemen et al.)
  - XP-1027: Sub-threshold RMP for impurity reduction (Canik, et al.) [ITER Support]
  - XP-1064: Enhanced Pedestal H-modes (Canik, et al)
  - XP-1004: Early error field correction (Menard et al.)
  - XP-1058: Squareness optimization (Kolemen, et al.)
  - XP-1005: Modification of early discharge evolution for impurity reduction (Menard et al.)
  - XP-1025 Combined vertical jogs & RWM for ELM Pacing (Canik, Loarte,) [ITER Support]
  - XP-1006: Development of high–f_{NI} discharges with reduced impurities. (Gerhardt et al.)

Progress on Some Performance Metrics in 2010

2010 2009 2008 2007 2006 2005 2004 2003 2002

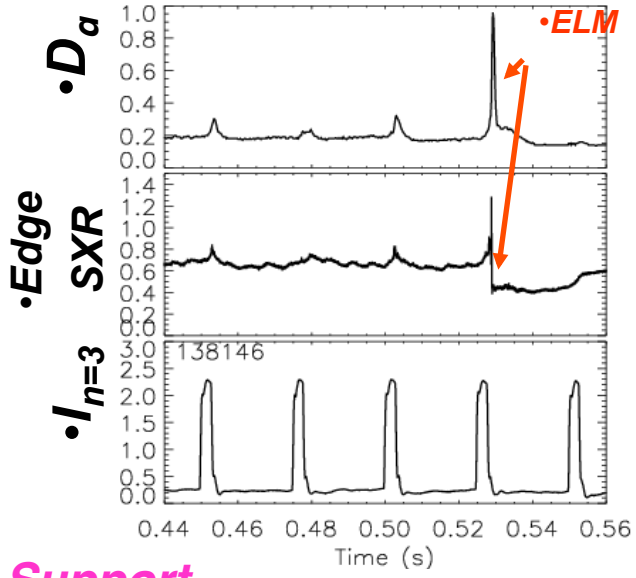


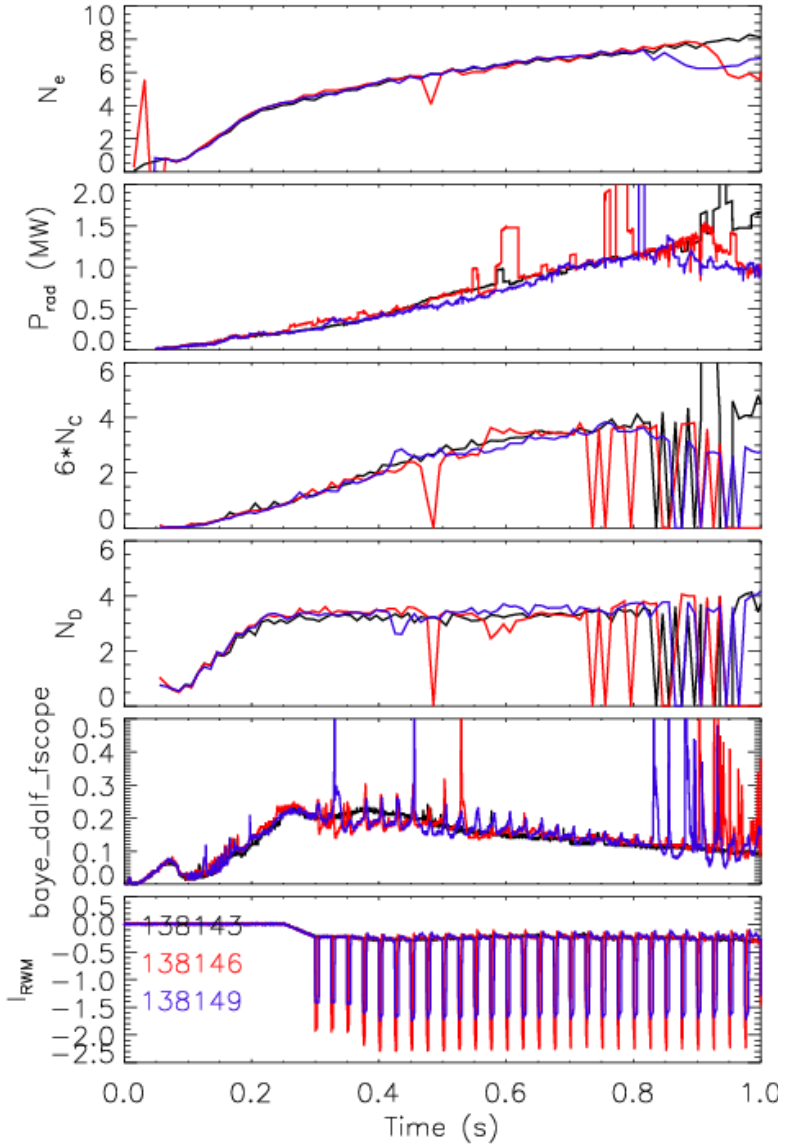
XP-1027: Impurity Screening with 3-D Field Pulses

J.M. Canik, R. Maingi

XP-2027: 3D field pulses below threshold for ELM-triggering ineffective for impurity screening

- Response to n=3 field observed in divertor D_α even when pulse is too brief or low amplitude to trigger ELM
- 3D field optimized for sub-threshold pulses
  - Maximize n=3 amplitude, duration while avoiding large ELMs
- Without ELMs, particle expulsion insufficient for impurity control
  - No dramatic impact on P_{rad} or carbon inventory evolution





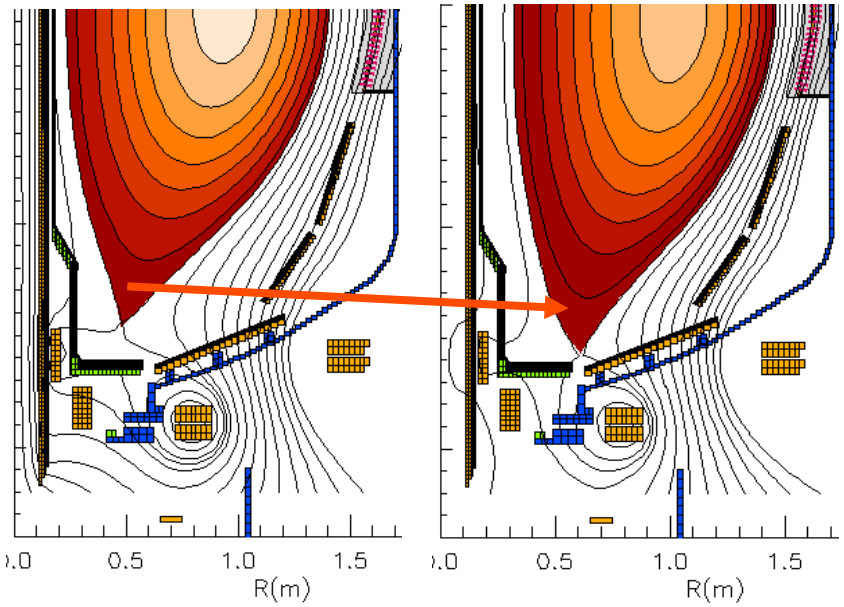
Direct ITER Support

Canik, et al.

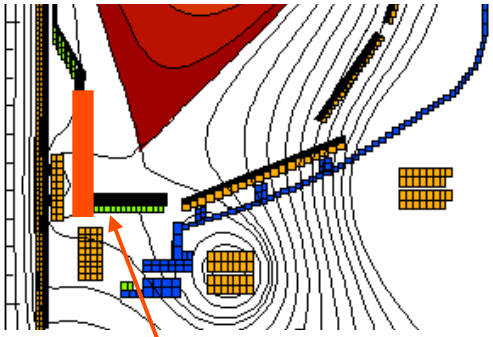
XMP-66: Optimization of the 4 Strike Point Controller

E. Kolemen, D. Mueller

• *Previous Year: Inner Strike Point Control*



•X-points bifurcation

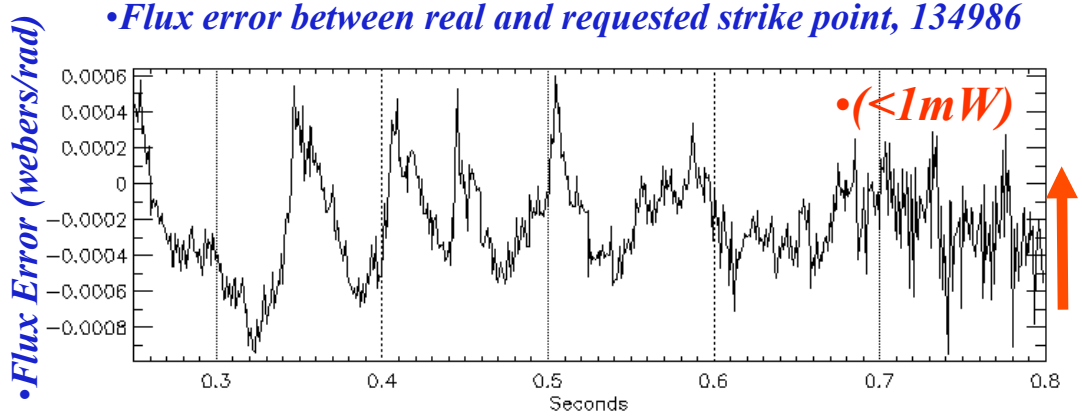


•Segment to control

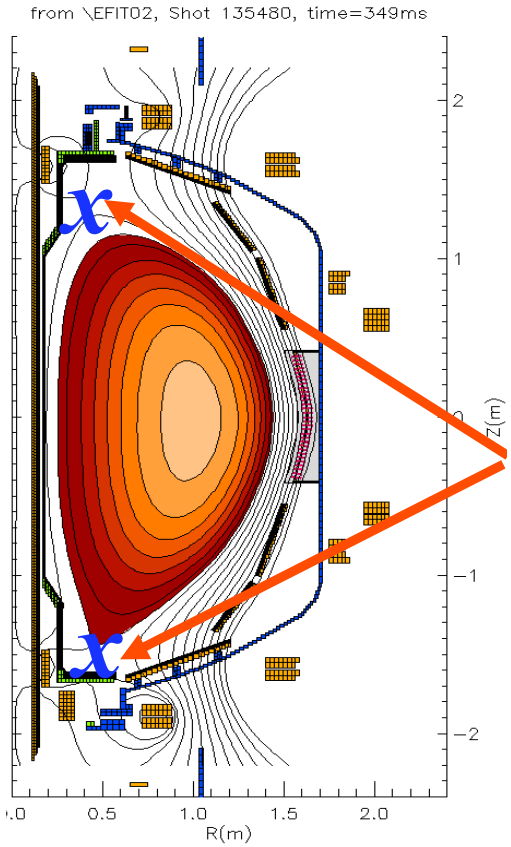
•inner strike point

- The OSP controller kept the controller at requested position but problems during the transition
- During the transient phase of the discharge, equilibrium bifurcated to a nearby solution with a low X-point.
- Algorithm was jumping from one solution to the other one.
- To make more stable plasma: Added inner strike point controller.

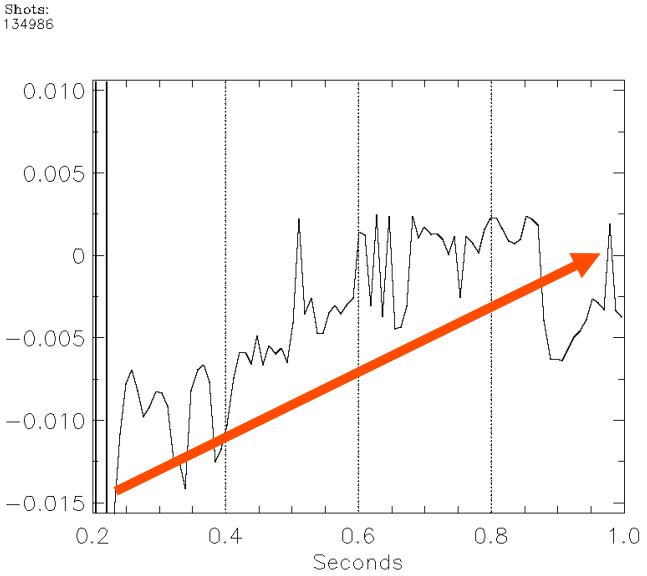
•Flux error between real and requested strike point, 134986



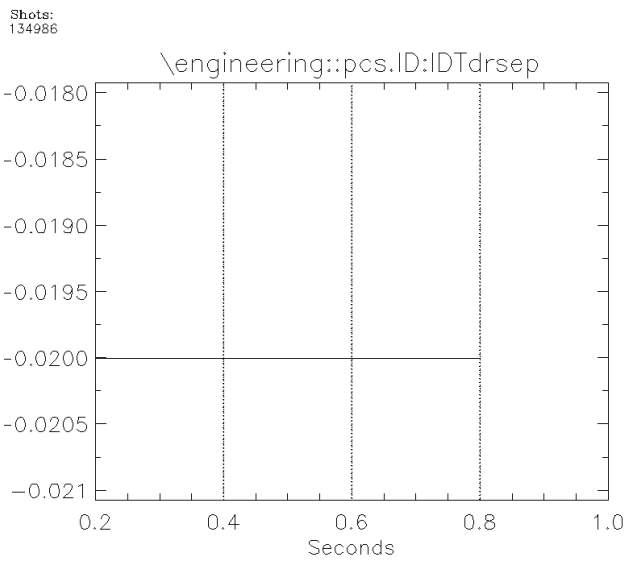
• *Improvement Need: Drsep Drifts When SP is Controlled*



•*Control Dr_sep drift via X-point controls.*



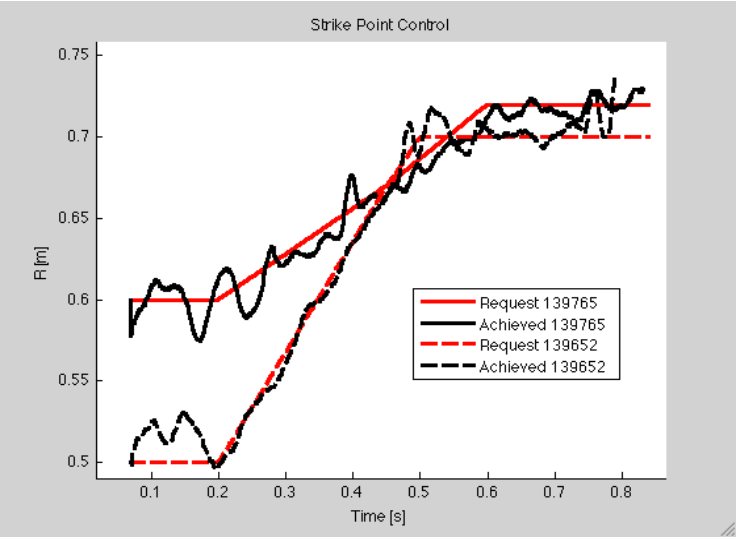
•*Dr_sep EFIT02 (cm)*

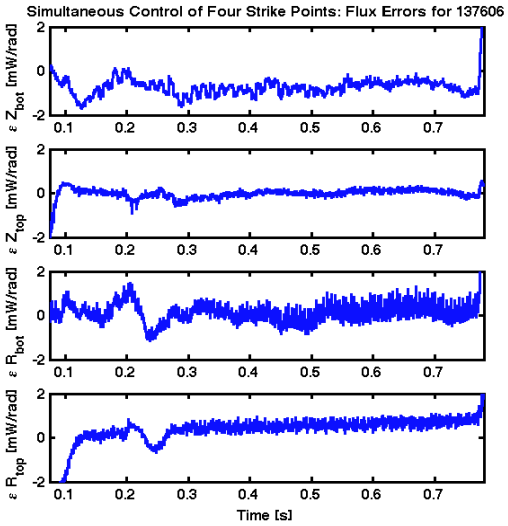


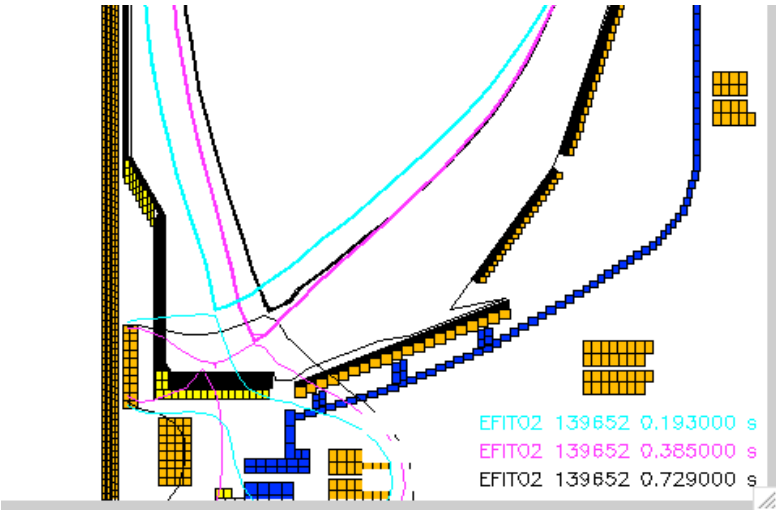
•*Dr_sep request (cm)*

- Problems with the drsep drifting to zero when SP control is on.
- If we can control both upper and lower X-point, drsep can be kept constant.

• XMP 66: Improvements for Shape Control

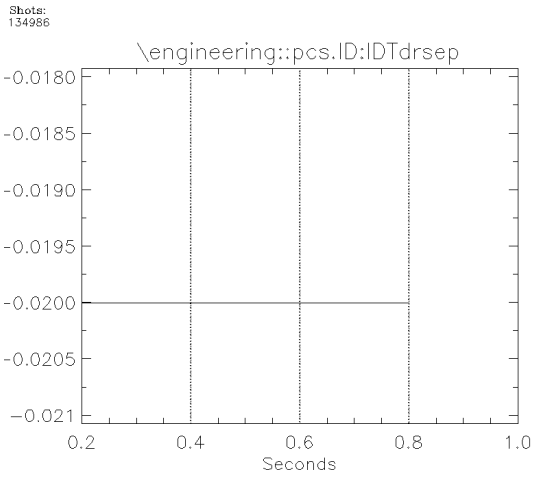


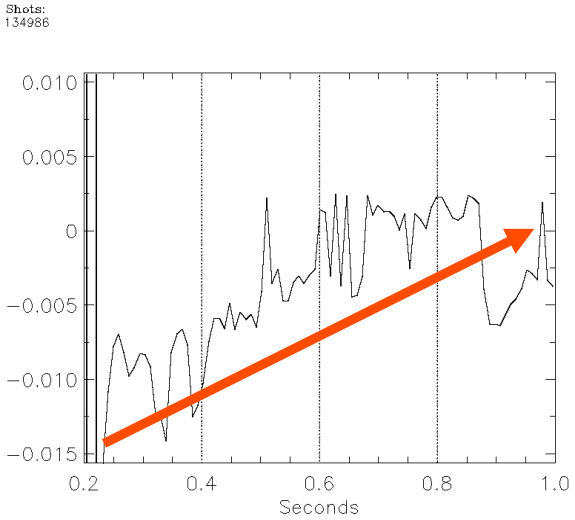


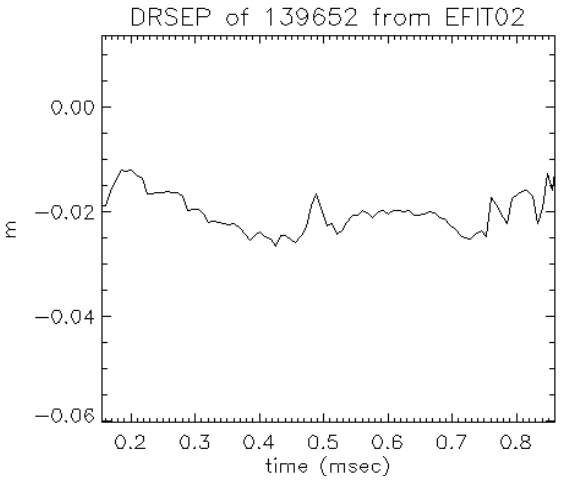


- *Control four strike point controllers with PF1AU, PF1AL, PF2U, PF2L*
- *Optimize/Tune PID gains.*
- *Added integral gain for PF3 coils.*
- *Scanned lower outer SP from 45 to 80 cm.*
- *Control hand-off (transition) was manually done.*
- *Smooth PF coil was achieved.*
- *The developed shot was used successfully in many experiments (>100 shots).*

• *Drsep Drift is Avoided with Improved Control*







•Dr_sep request (cm)

•Dr_sep EFIT02 without unimproved lower only SP control (cm)

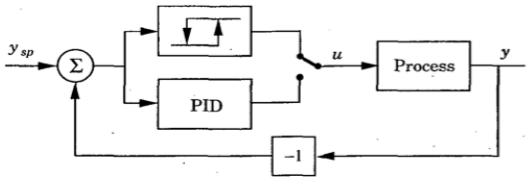
•Dr_sep with improved upper/lower SP control (m)

- Previously: roblems with the drsep drifting to zero when SP control is on (single SP control).
- Control of both upper and lower X-point means that drsep can be kept constant.

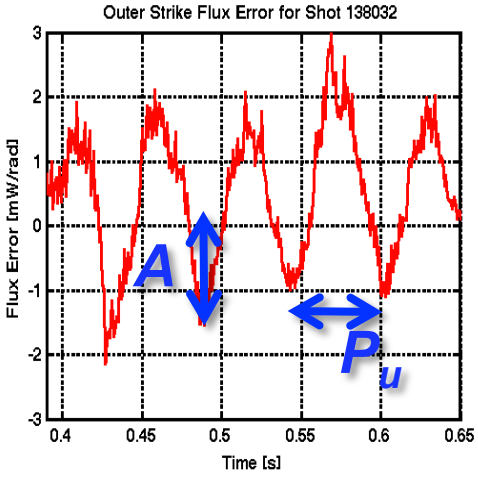
XP-1003: Combined OSP Radius and X-Point Height Control

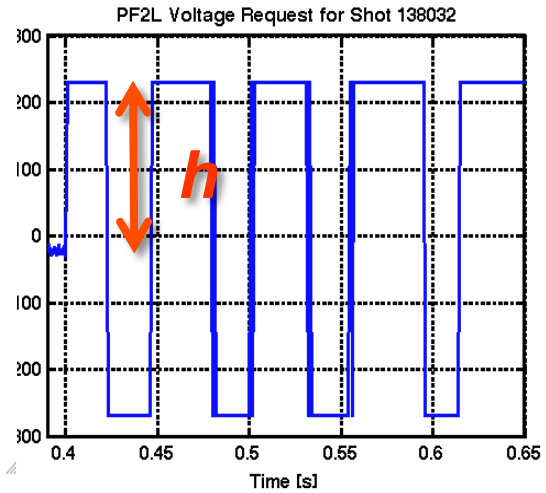
E. Kolemen, D. Mueller

• XP 1003: Relay Feedback Automatic Control Tuning Used For Combined OSP Radius and X-Point Height Control



•*The relay-feedback control diagram.*





•***Relay-feedback system identification***

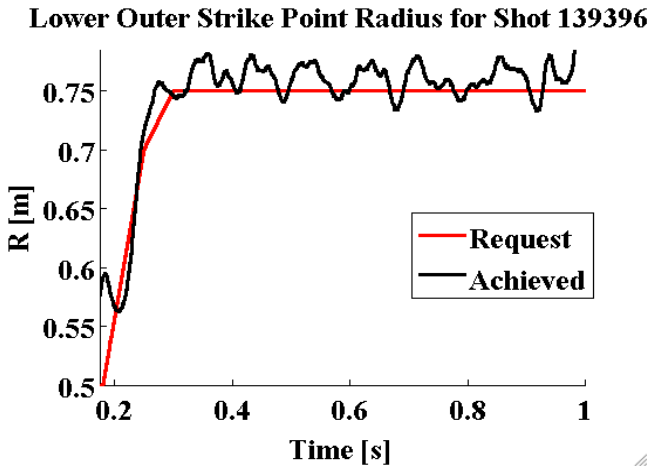
	K_c	τ_I	τ_D
P	$0.5K_{cu}$		
PI	$0.45K_{cu}$	$P_u/1.2$	
PID	$0.6K_{cu}$	$P_u/2$	$P_u/8$

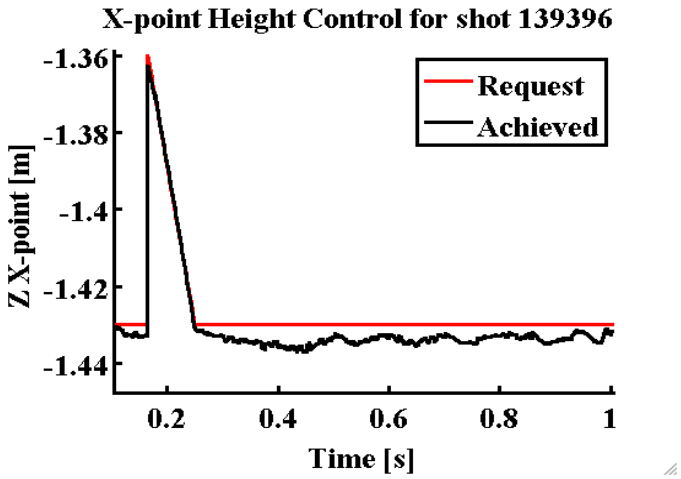
•***TABLE I. THE ZIEGLER-NICHOLS TUNING METHOD.***

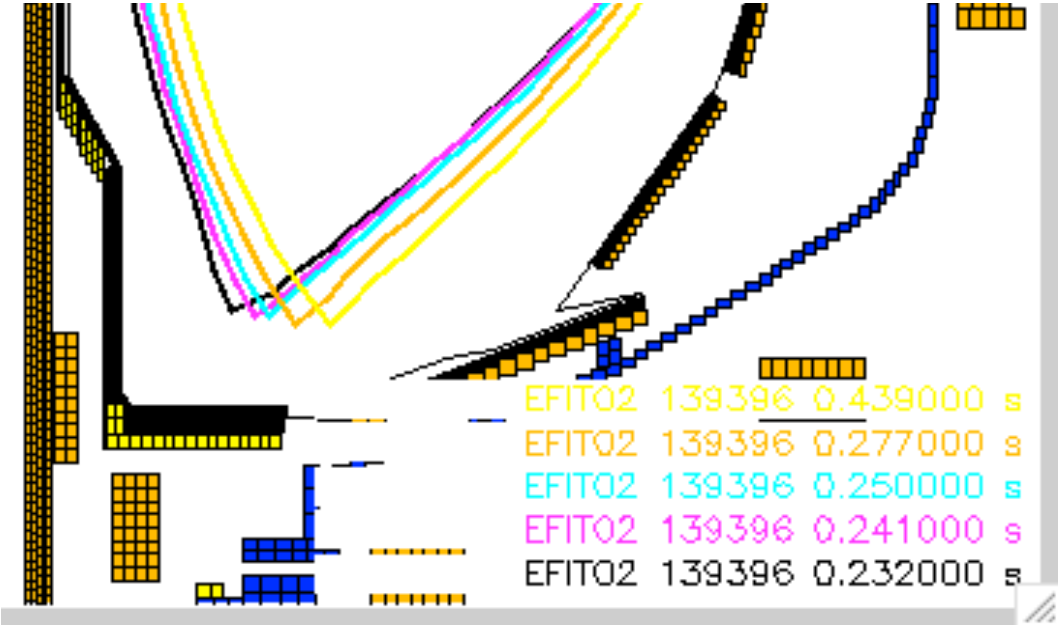
K_{cu} =4h/(πA)

- *Developed the combined X-point height strike point radius control*
- *Tuned by using Relay-Feedback.*
- *Do sequential tuning: first one controller then the other.*
  - *First OSP controller.*
  - *Then XP Height controller.*
  - *Then OSP again…*
  - *Then XP Height again…*
  - *Then…*

XP 1003: X-point Height / Strike Point Control Achieved







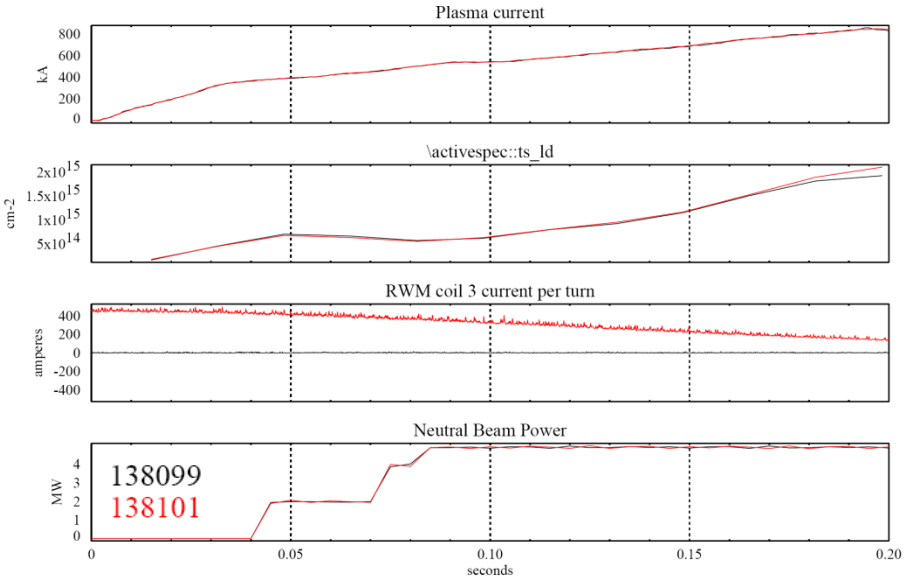
- *Achieved <1 cm X-point height error and <2 cm strike point radius error.*
- *These shots were used in XP 1041a (LLD Autoactivation)*
- *There can be transient issues when controller is turned on… could be improved with more effort.*

XP-1004: Early Error Field Correction

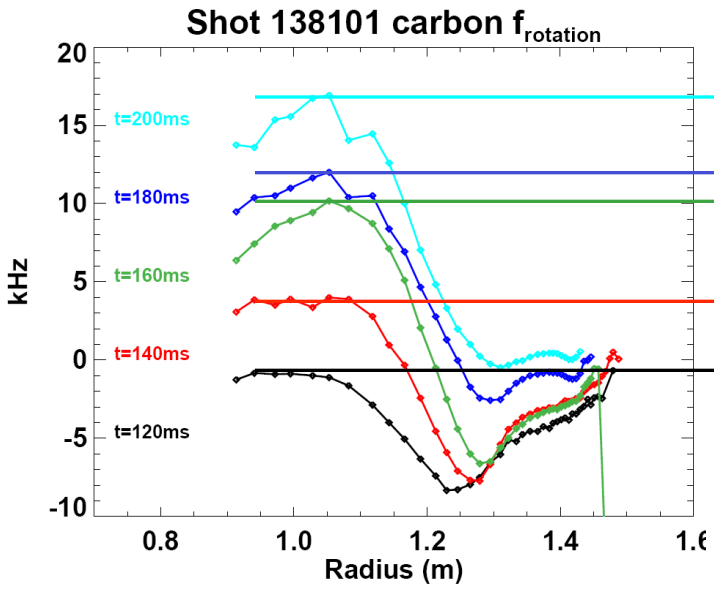
J. E. Menard

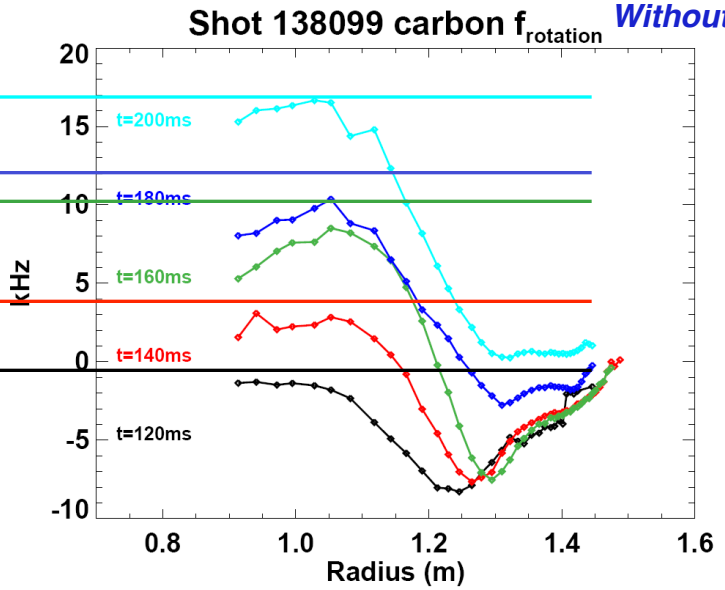
XP-1004: Low density plasmas with and without early EFC show early EFC increases rotation 10-20% for t=120-180ms

- Delay of early H-mode by reduced early fueling reduces density by 30-40% at t=0.2s (vs. reference)
  - Similar to what typically happens with increased LITER evaporation
- Additional EFC phase, amplitude scans (in 2011) might be able to further increase rotation at reduced density.



With Correction



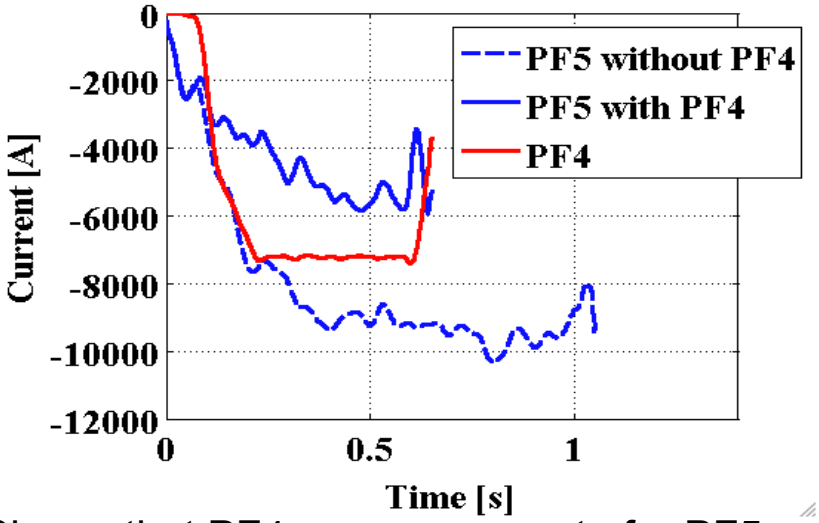


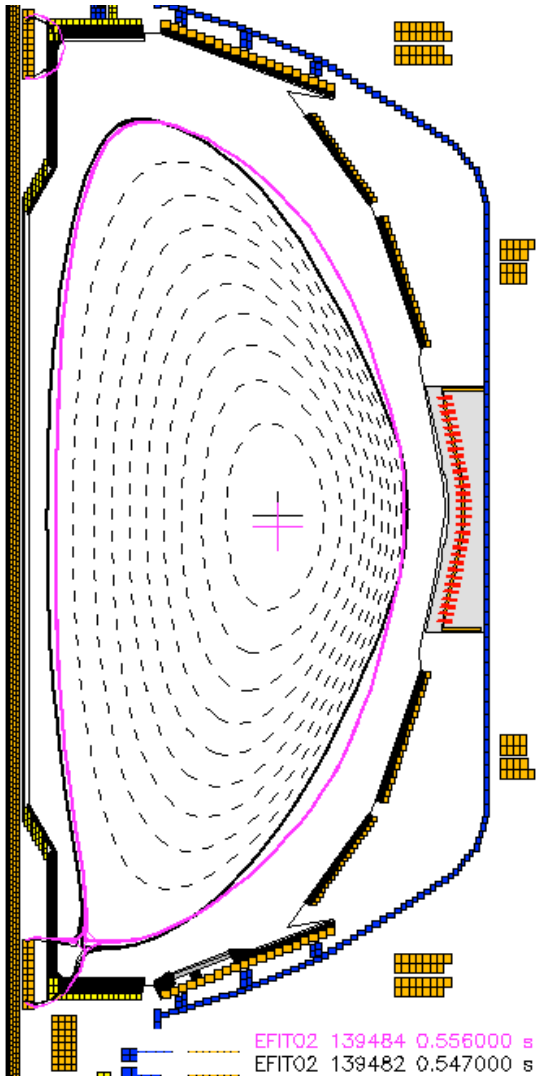
Without Correction

XP-1058: Effect of PF-4/Squareness on High Performance Plasmas

E. Kolemen, D. Mueller

• XP 1058: Effect of Squareness/PF4

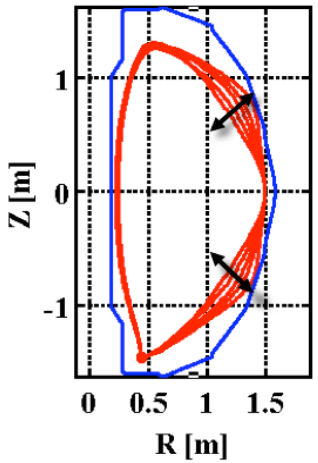




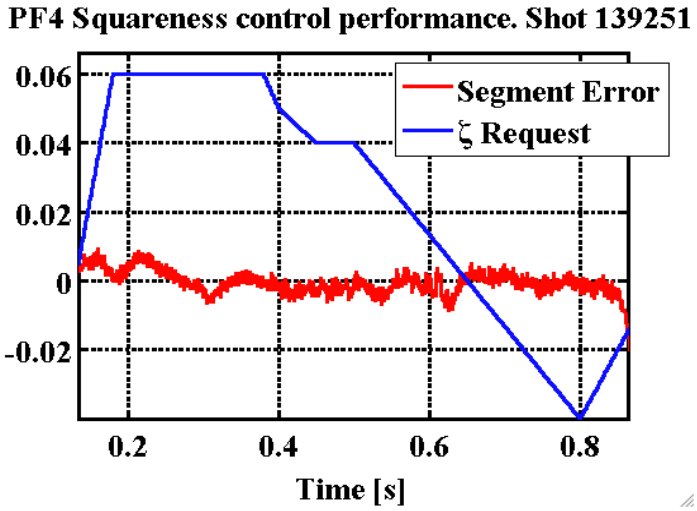
- Shown that PF4 can compensate for PF5.
  - Important for NSTX-Upgrade
- Used PF4 in
  - Preprogrammed mode
  - Feedback mode to control squareness.
- Shots with PF-4 appeared to have good confinement, maybe lower β-limit?
  - Rotation damping appeared strong (RWM control problem?)
  - Need MSE constrained reconstructions for no-/with- wall stability analysis.
  - TRANSP runs for confinement assessment

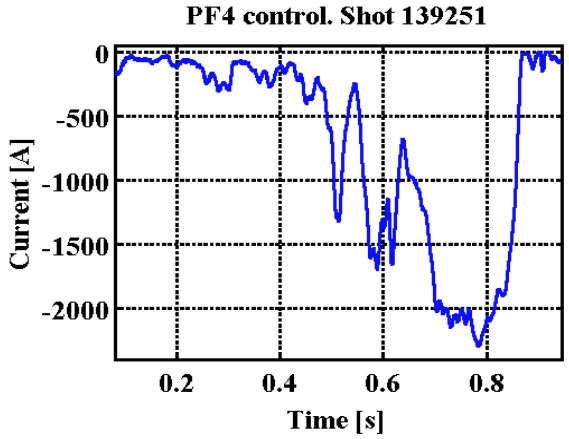
• XMP Control Results: PF4 Initial Squareness Control

- Change squareness request while PF4 control on with new segment.
- Good control with no bias
  - PF3 on the other hand has bias due to controlling more than just squareness (and not having integral gain)
- Below is a test where we changed the squareness wildly and PF4 responded well.



•The ISOLVER simulated effect of varying PF4 from -10 kA to +10 kA on the plasma boundary. And the Control Segment for squareness.



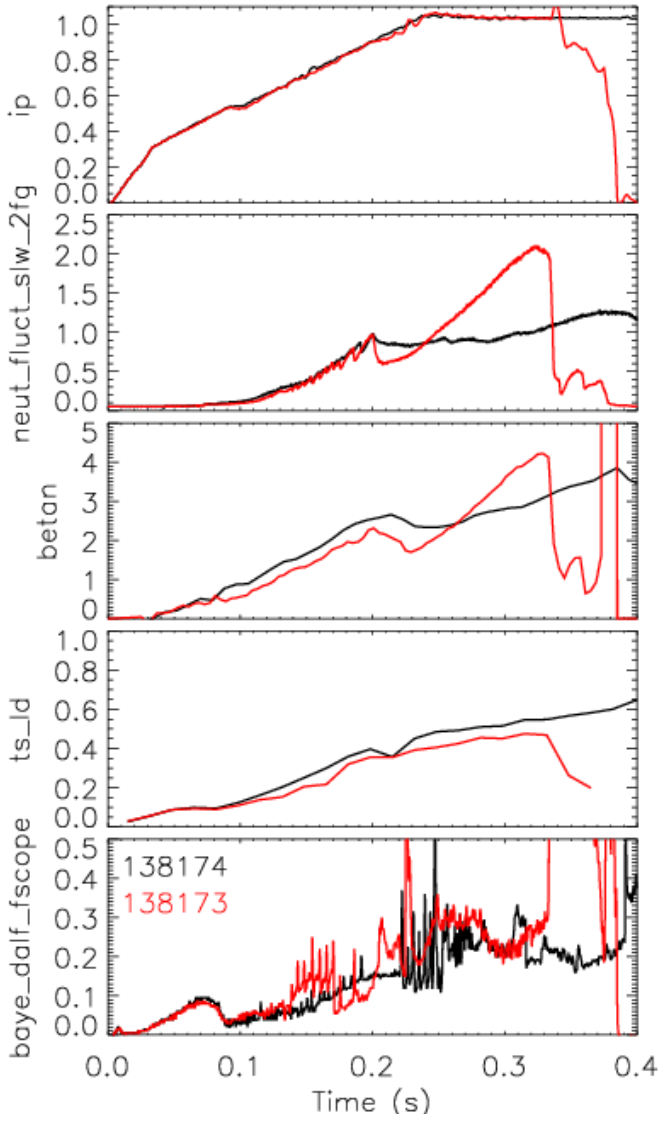


XP-1064: Development of Long-Pulse EPH Mode Plasmas

J.M. Canik, R. Maingi, S.P. Gerhardt,…

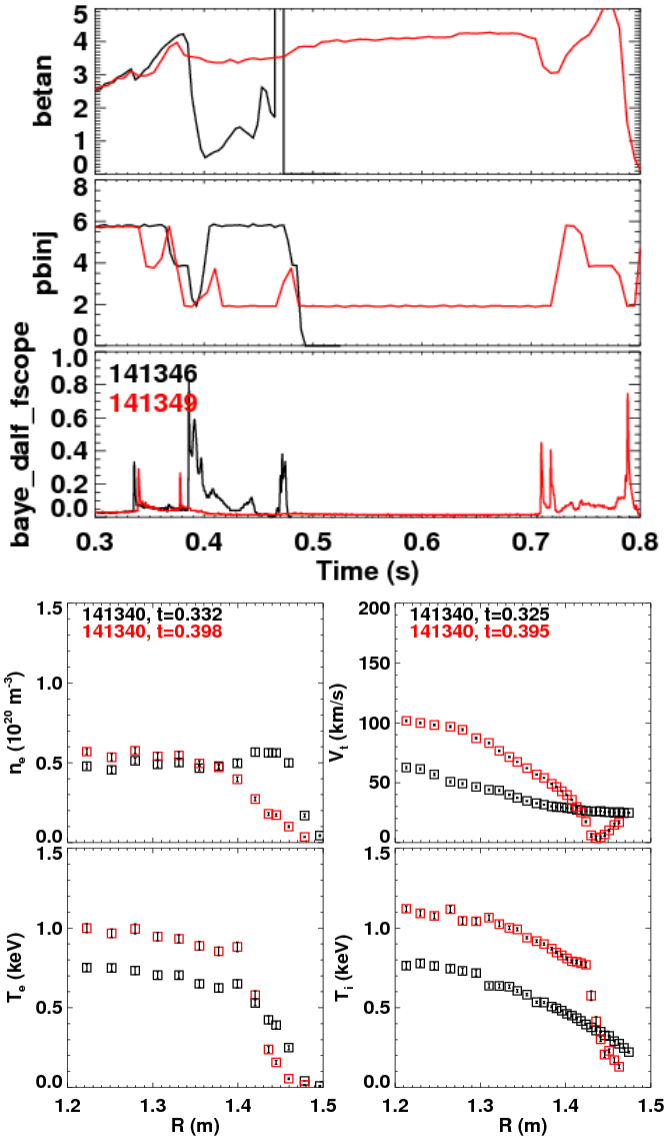
First EPH Day Experiments Tried to Use n=3 Pulses, then Tried to Optimize an SGI+Current Ramp Scenario

- XP Goals: trigger EPH, extend with advanced control techniques
  - Lithium, SGI to facilitate
  - Triggered ELMs (w/ n=3 field) to initiate
  - β, RWM feedback to extend
- Triggering of ELMs with 3D fields did not initiate EPH
  - Did produce high confinement phases following ELMs ($H_{98ipby2}$ ~ 1.15), but edge profiles do not indicate EPH
- With SGI fueling, EPH was observed during I_p ramp
  - Unable to extend into flat-top (adjusted I_p,B_t, did not attempt β control this day)



Second EPH Try Attempted To Use β_N Control To "Catch" EPH Mode

- Natural EPH phases commonly attained at reduced q_{95}
  - No SGI or n=3 triggers used
  - Occurred (early) in flat-top
- β-feedback control attempted to extend EPH
  - Aggressive feedback parameters (gain and target beta) successful in rapidly dropping power following transition
  - Early disruption avoided, but second ELM ended EPH.
  - Possible path forward: lots of Li to avoid all ELMs, trigger a single ELM and EPH, use β_N control to grab and sustain configuration

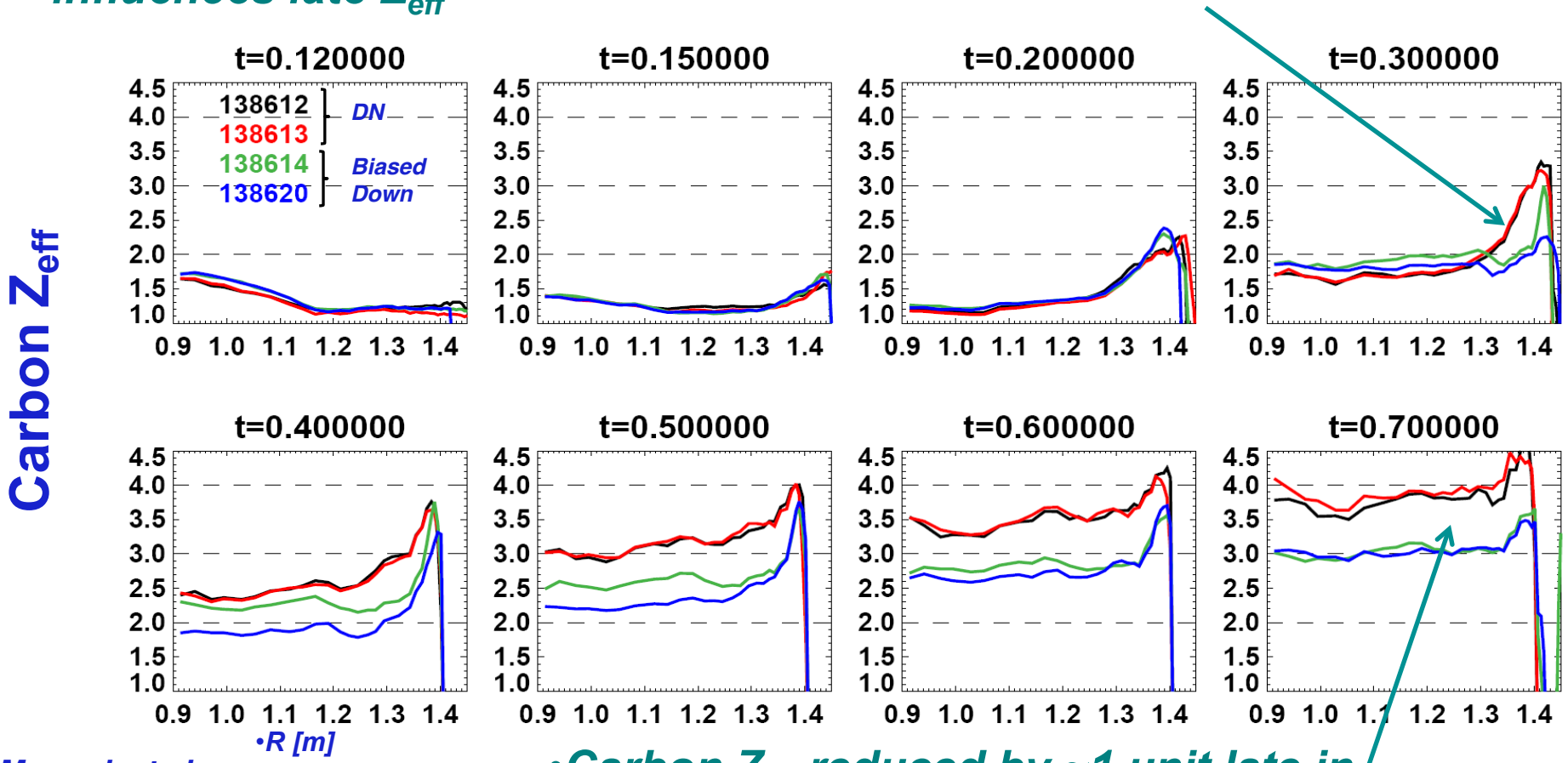


XP-1005: Effect of Up/Down Magnetic Balance on Impurity Accumulation

J. E. Menard

ΔR_{SEP} change from -7mm to 0 reduces impurity confinement and/or generation and reduces C Z_{eff} by ~1

- *Like 2009 result, size of H-mode C impurity "ear" near t=0.3s influences late Z_{eff}*



Menard, et al.

- *Carbon Z_{eff} reduced by ~1 unit late in*

Motivated testing combinations of this + divertor D puff+…

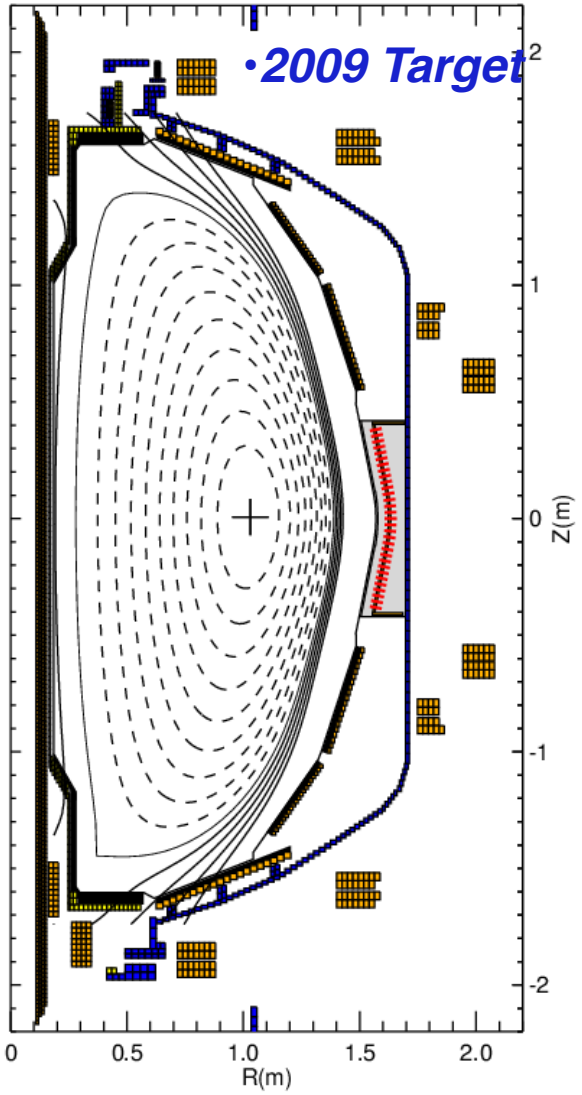
XP-10XX: High β_P Discharge Development (Reduced Impurities and Plasma Current)

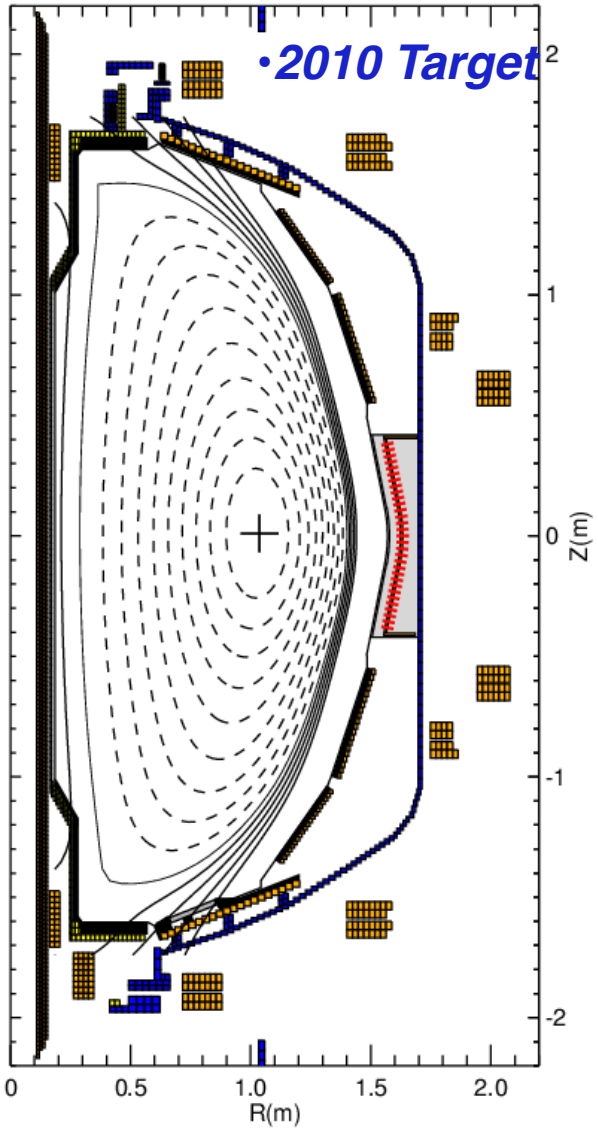
S.P. Gerhardt, et al.

Overview

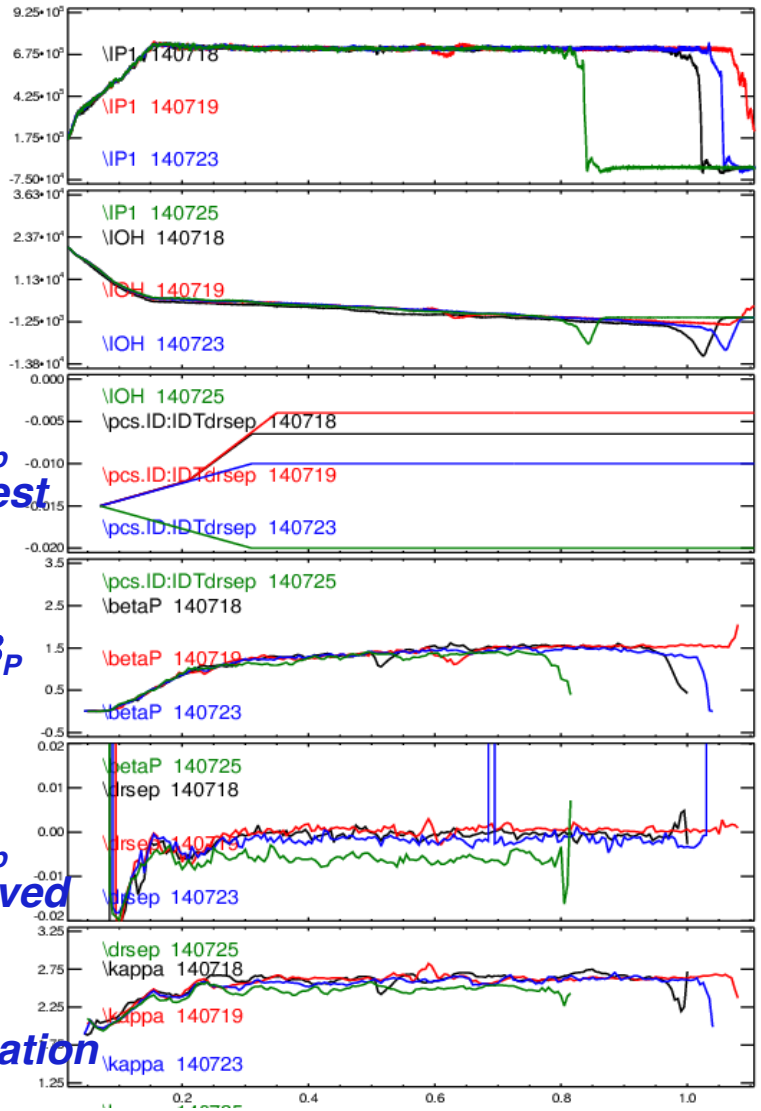
- Goal was to take best high-β_P shots from 2009, & use impurity reduction techniques to reduce Z_{eff}.
- Tried three things:
  - dr-sep scans
  - ELM triggering with RMP
  - Divertor gas puff (not in this presentation)
- None were clearly successful in reducing impurities
- Low I_P part of the XP that is not yet finished.

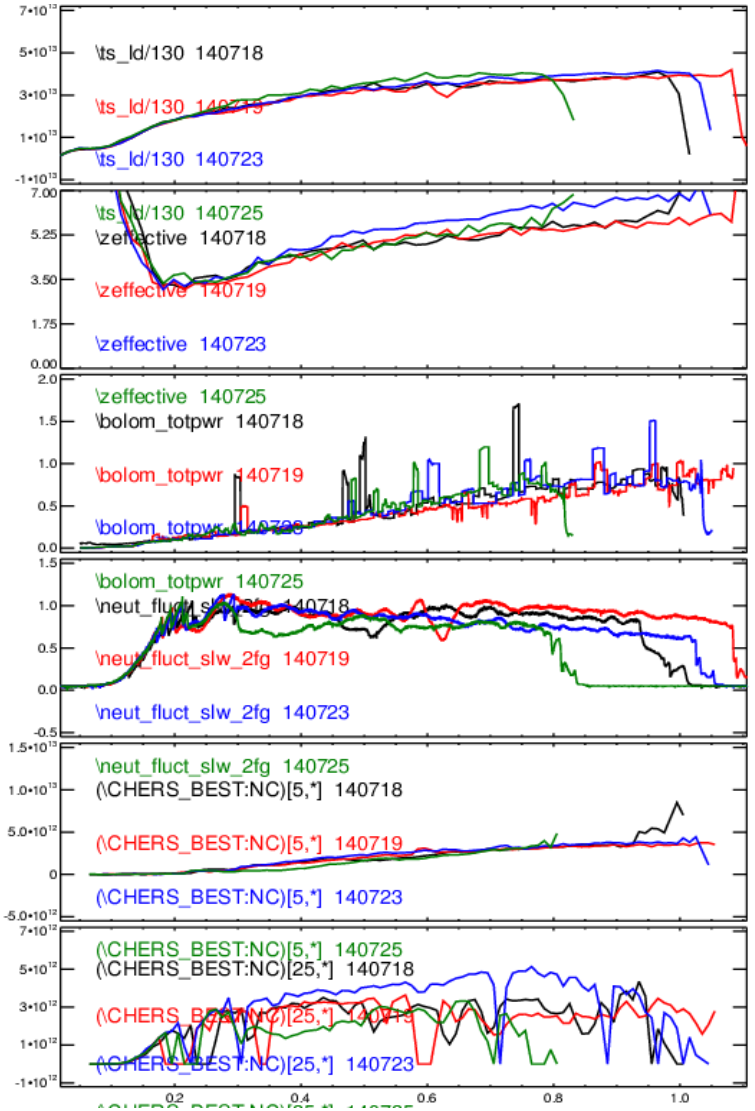
Shape Similar to Last Year





dR_{sep} Scan Alone Did Not Show Any Improvement in Performance (Always Near DN)

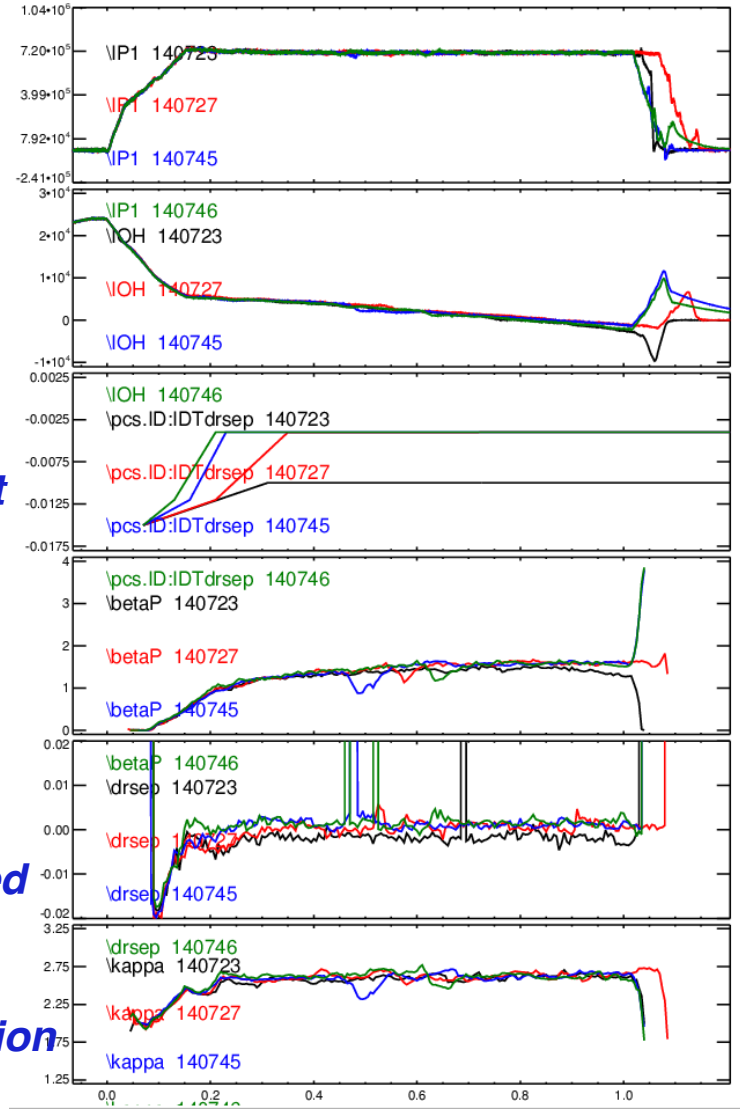


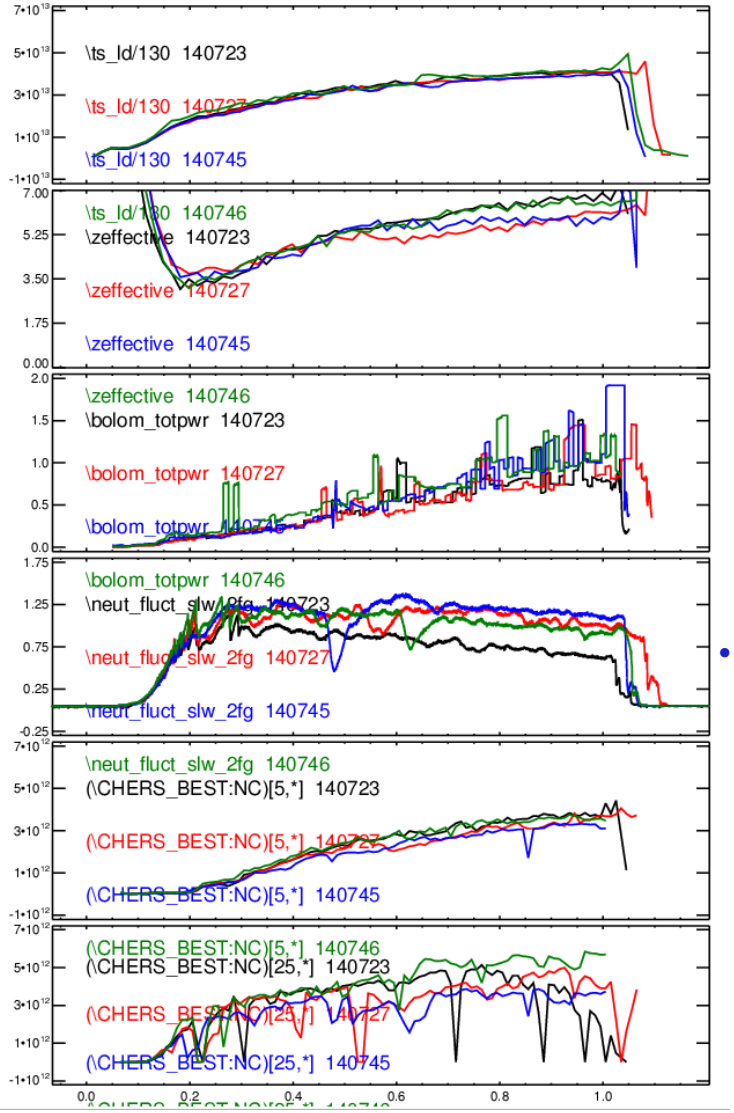


- I_P
- I_{OH}
- ΔR_{Sep} Request
- β_P
- ΔR_{Sep} Achieved
- Elongation
- Density
- Z_{eff} From VB
- Radiated Power
- Neutrons
- Central Carbon Density
- Edge Carbon Density

Worked To Bring The dR_{Sep} Ramp as Early as Possible

- I_P
- I_{OH}
- ΔR_{Sep} Request
- β_P
- ΔR_{Sep} Achieved
- Elongation

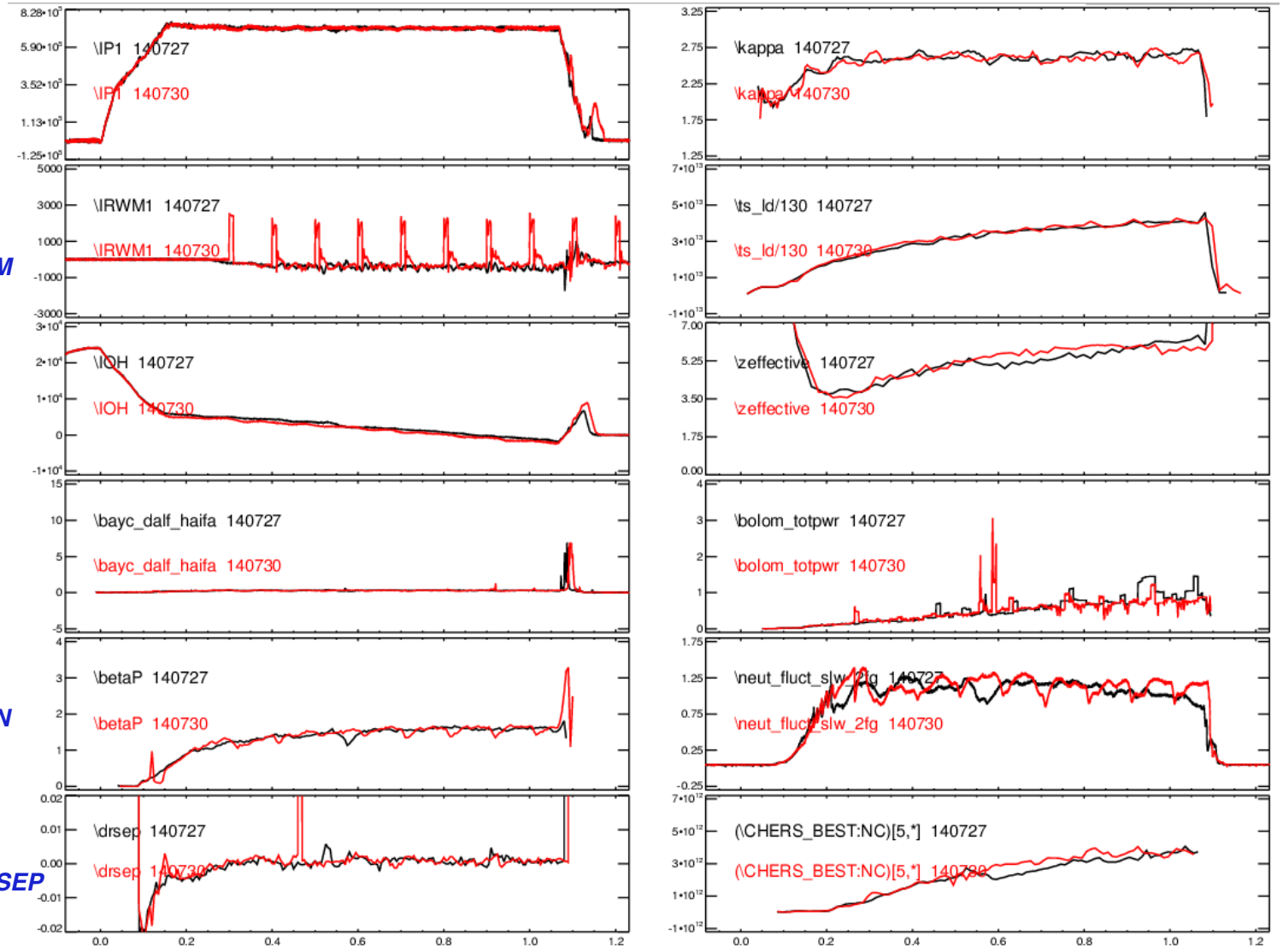




- $Density$
- Z_{eff} From VB
- Radiated Power
- Neutrons
- Central Carbon Density
- Edge Carbon Density

RMP Pulses Were Not Able To Trigger ELMs In This Scenario (I)

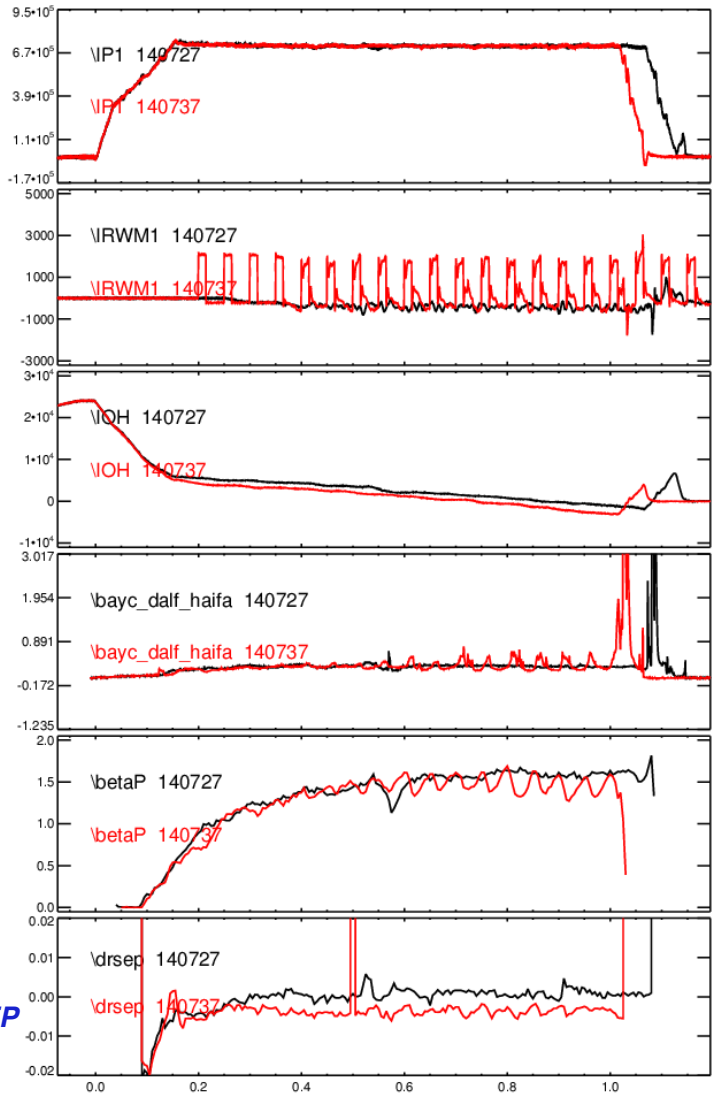
- I_P
- I_{RWM}
- I_{OH}
- D_α
- β_N
- ΔR_{SEP}

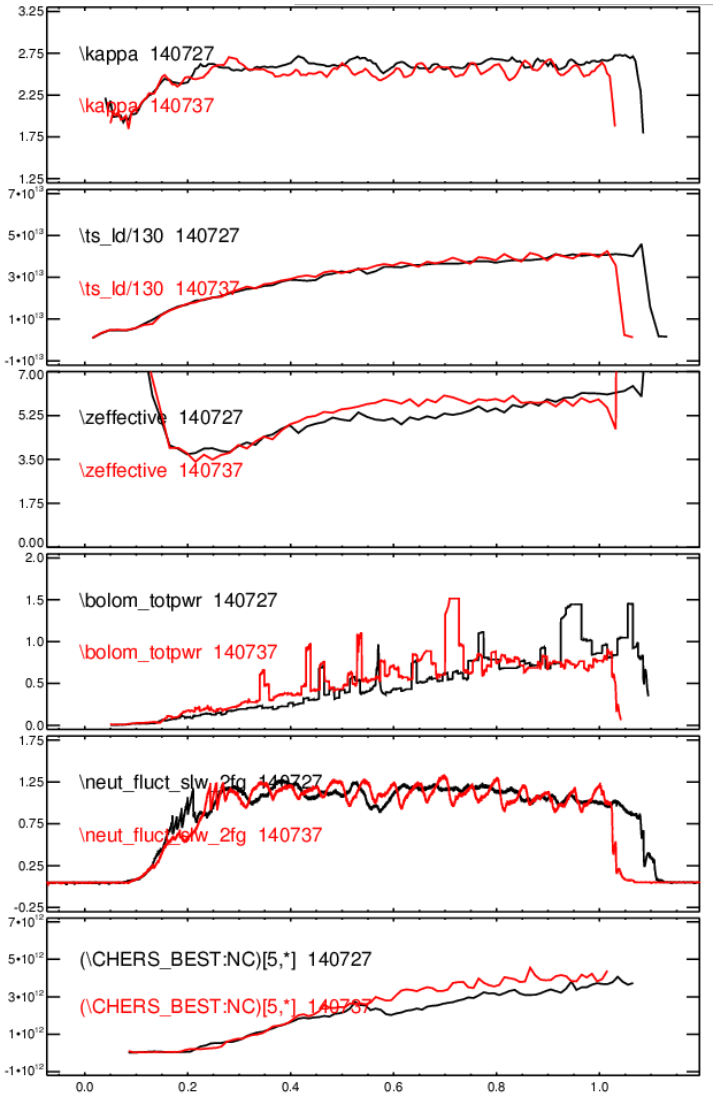


- Elongation
- Density
- Z_{eff} From VB
- Radiated Power
- Neutrons
- Central Carbon Density

RMP Pulses Were Not Able To Trigger ELMs In This Scenario (II)

- I_P
- I_{RWM}
- I_{OH}
- D_α
- β_N
- ΔR_{SEP}





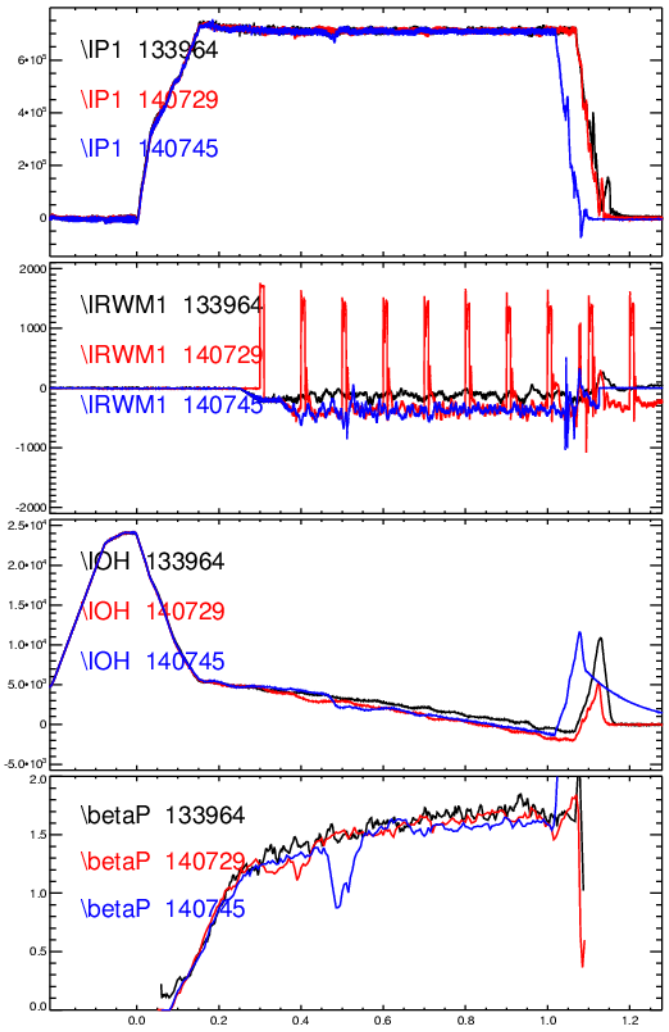
- *Elongation*
- *Density*
- *Z_{eff} From VB*
- *Radiated Power*
- *Neutrons*
- *Central Carbon Density*

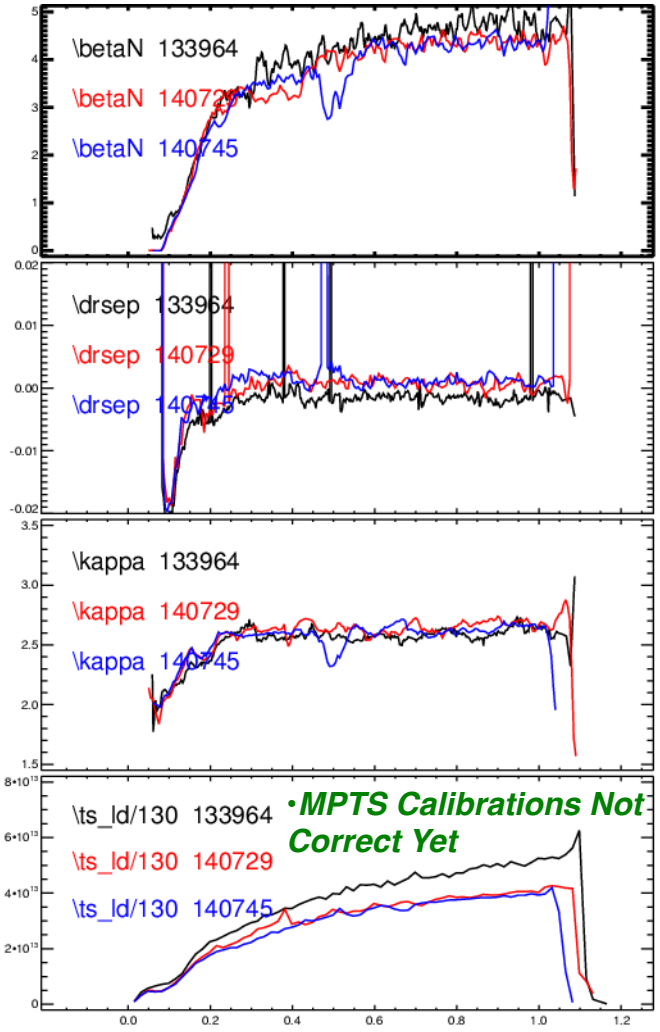
Why Didn't ELM Pacing Work?

- Too much lithium?
  - Were using 300 mg/shot, which is a lot more than previous tries at this.
- Strong shaping?
  - Even more biased down shots didn't have triggering.
- Lower current?
  - Maybe
- Plasma to far from coils?
  - Previous triggering experiments used a ~10 cm outer gap, this XP was ~15 cm.

Almost Matched the 2009 Best Shot, No Improvements Compared to them.

- I_P
- I_{RWM}
- I_{OH}
- β_P





- β_N
- ΔR_{SEP}
- Elongation
- Density

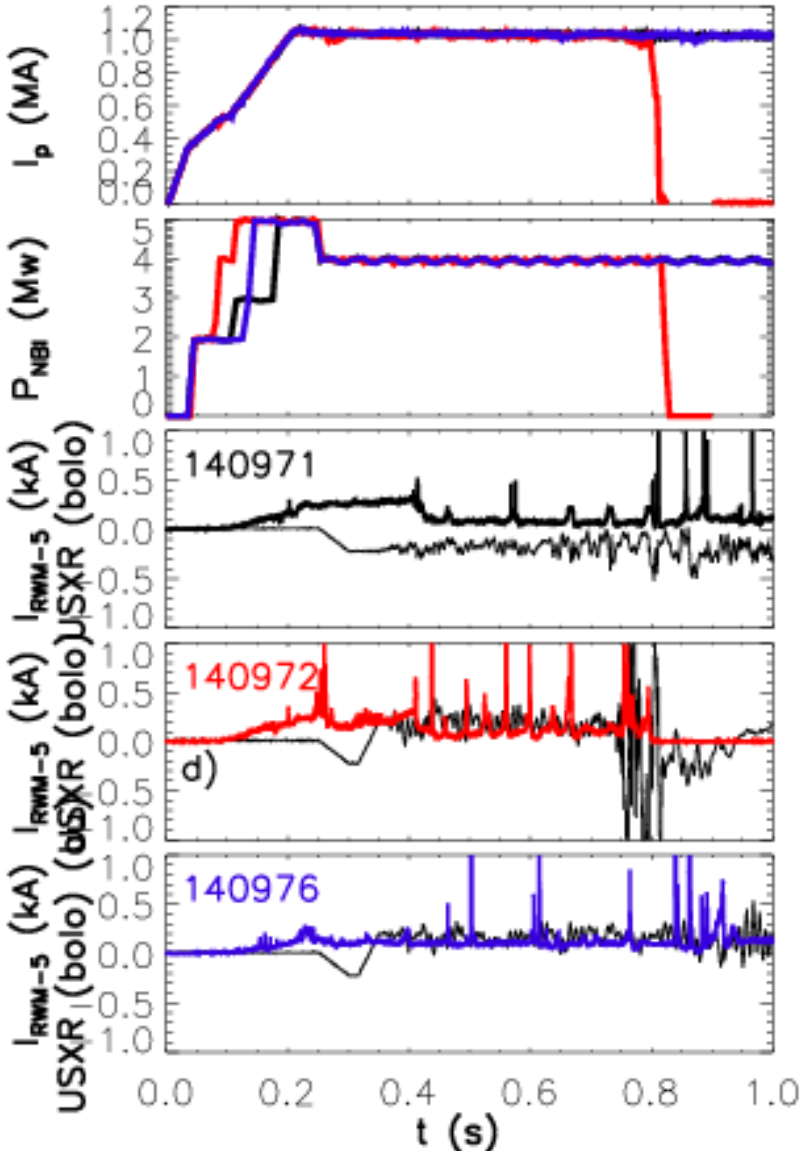
•2009 2010 2010

XP-10XX: ELM Pacing Through Combined Vertical Jogs and RMP

J.M. Canik, A. Loarte, S.P. Gerhardt,...

VJ+RMP Demonstrated to Work, But Physics Study is Largely Incomplete

- XP Goal: test if combining vertical jogs and n=3 field can trigger ELMs at reduced jog size, field amplitude
- First run provided proof-of-principle
  - Jogs alone: no/few ELMs
  - Jogs + n=3: several ELMs
  - n=3 alone: fewer ELMs
- Second run had trouble with L-H transition timing
  - Largely repeated results from first day: below threshold jogs made ELMy with n=3 field
  - Shot list not completed



Note on ASC Tasks For Final Month

- Some cleanup work on beam XPs:
  - XP-1058: Try positive squareness in XP-1058
  - XP-1006: Try reduced I_P targets for higher f_{NI}. (1/2 day)
- Try to start 2 XPs
  - XP-1071: Development of high aspect ratio and elongation scenarios.
    - Supports PPPL "Pilot Plant" study, various FNS options, NSTX-U.
  - XP-1007: HHFW Heating in H-mode.
    - Direct contribution to ASC "Low Collisionality" Milestone in 2011.
    - Tests HHFW drive impurity reduction (PAC request).