ASC XP-823

Error Field Correction and Long Pulse

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Part 1

Determine the source of, and optimal correction for, the observed n=3 error field.

Part 2

Optimize the n=1 feedback time constant and gain for optimal pulse length at high-β.

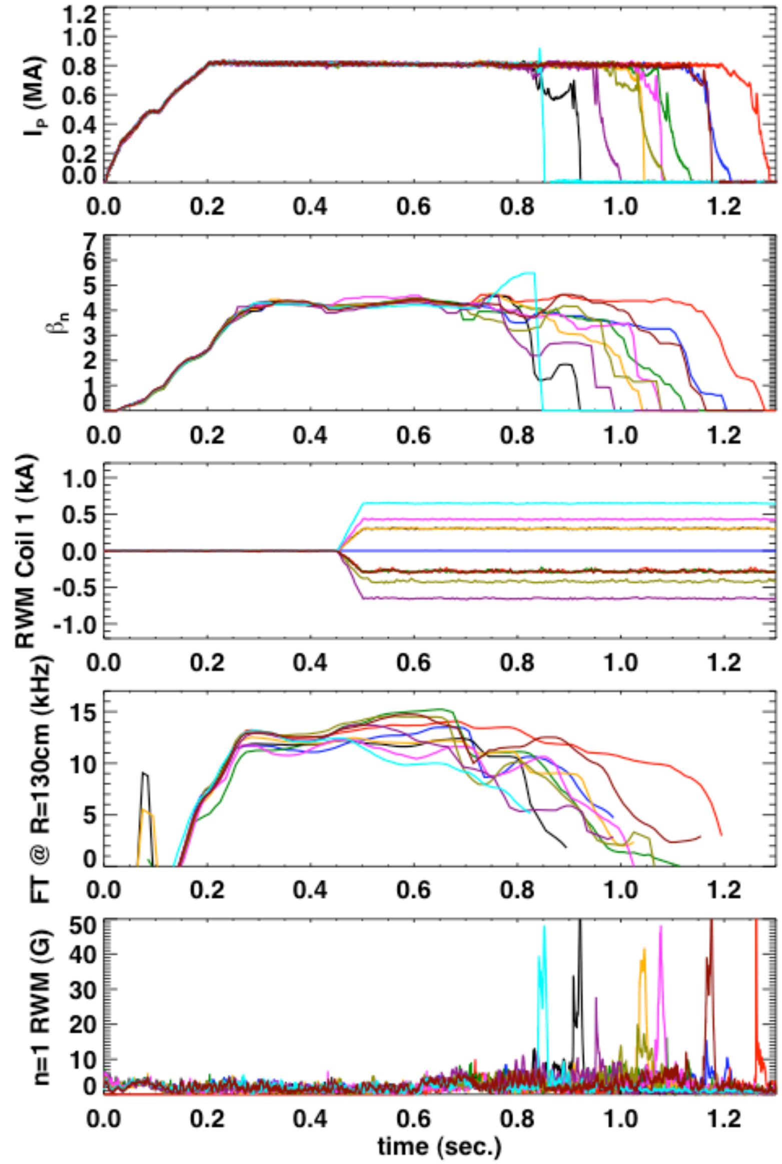
n=3 Applied Fields Can Improve Discharge Performance

- Impact on rotation appears as soon as n=3 field is turned on.
    - Some polarities of n=3 cause acceleration, others braking
      → there is an intrinsic n=3 error field.
- Pulse length improves with the n=3 polarity yielding maximum rotation.

What determines the required n=3 correction level?
The plasma current?
The PF 5 coil?

Try to Find The Optimal Correction at 750kA, 900kA, and 1100kA

Data from XP 701



Method Utilized to Determine the n=3 Correction

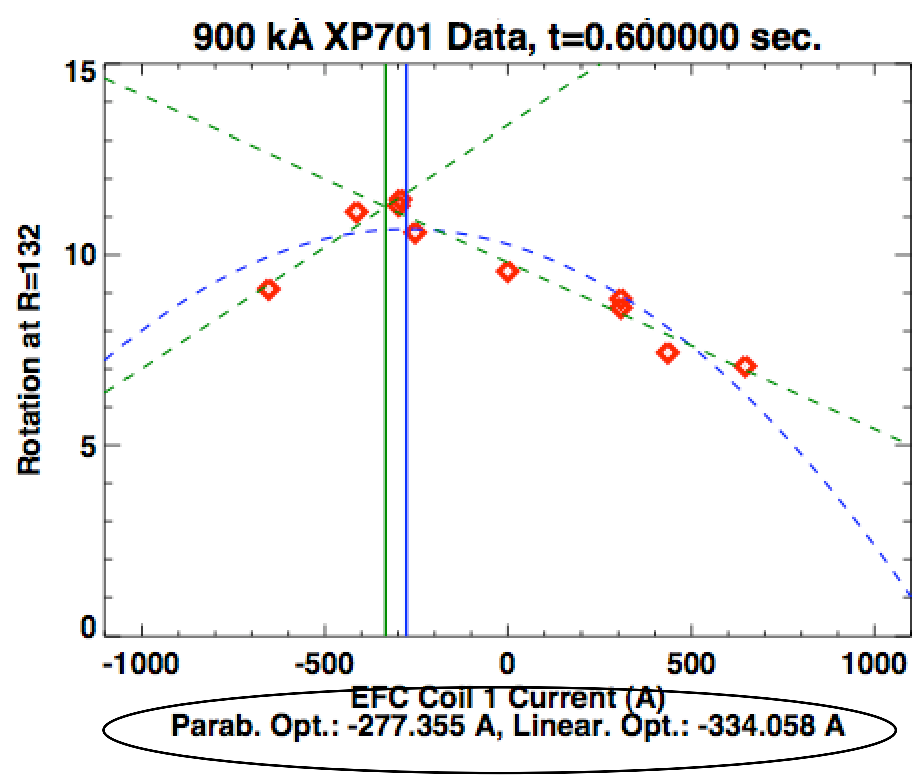
• Average the rotation over three CHERS time points before the β collapse.

• Plot rotation at various radii as a function of RWM coil current.

• Fit the data as (see to right):
  • A simple parabola. (blue)
  • Two lines on either side of the maxima (green)

• Estimate the optimal current from:
  • Maxima of parabola
  • Intersection of the lines.

XP	I_p (kA)	Average three time points surrounding:
XP 823	750	0.43
XP 701	900	0.6
XP823	1100	0.42



Intersection Method (green)

• More Biased Toward the Maximum Single Point

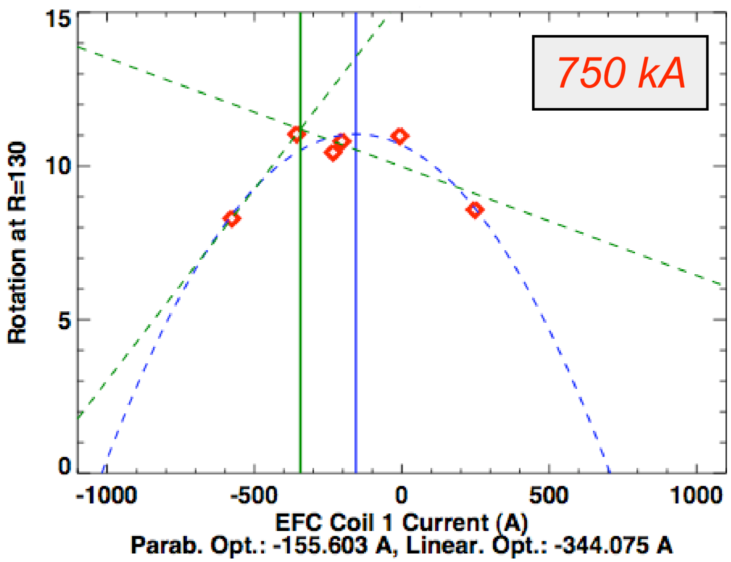
• Typically Yields Higher Correction Currents

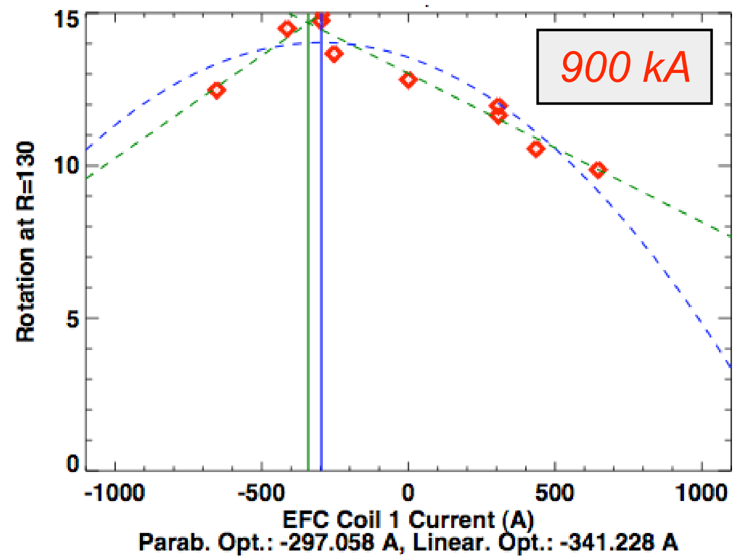
Shots Used in Analysis For Optimal n=3 Correction

Shot	Plasma Current	XP	EFC Coil 1 Current
124411	900	701	0
124428	900	701	-250
124430	900	701	-300
124432	900	701	306
124433	900	701	306
124434	900	701	434
124437	900	701	-413
124438	900	701	-650
124439	900	701	650
124440	900	701	-300
128039	750	823	0
128043	750	823	-200
128046	750	823	250
128047	750	823	-230
128048	750	823	-350
128049	750	823	-576
128895	1000	823	0
128896	1000	823	-275
128897	1000	823	316
128898	1000	823	650
128899	1000	823	-650
128900	1000	823	-1000
128901	1000	823	970
128902	1000	823	-400

- Shots span two years.
- No n=1 DEFC or RWM feedback in any of these.
- XP701 data used gap-control algorithm, XP823 used Isoflux.

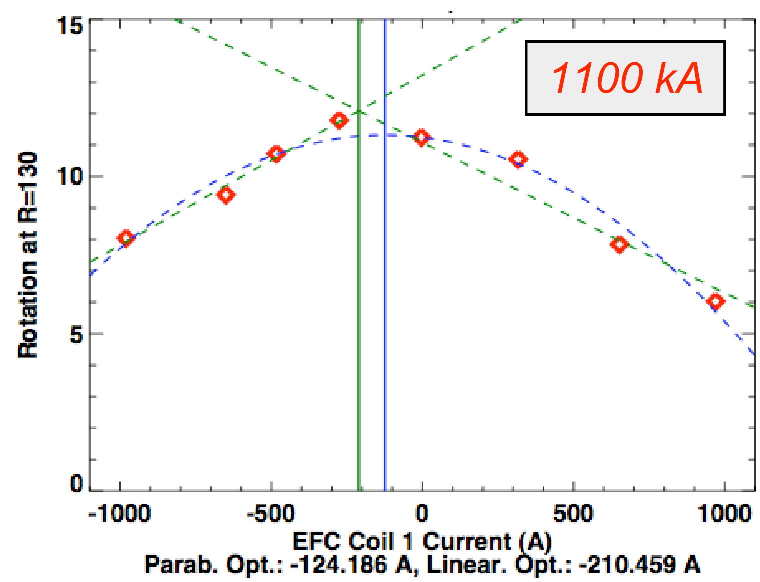
Example Results for the Three Currents





Rotation at R=130 shown, but similar results at larger radii.

Two methods don't always agree, parabola is typically better.



Pull it all Together…No Clear Trends

I_P (kA)	PF 5 Current (kA)	Typical Correction From Parabolic Fits (A)	Typical Correction From Linear Intersections (A)	SPG's Recommended Correction (A)
750	8255	175	300	250
900	9065	250	340	300
1100	9834	115	200	200

- *Recommended correction based on both rotation optimizations and pulse length.*
- *1100 kA optimizes to smaller correction than 750kA & 900kA→ inconsistent with I_P scaling and difficult to reconcile with PF5.*
- *Maybe the TF?*

- *Probably OK to always use 250 A n=3.*
- *Toroidal phase and poloidal spectrum of correction not optimized…need NCC for that.*

Feedback Algorithms Upgraded at the Beginning of 2008 Run

Change 1: EF/Mode Identification

Before: A single n=1 amplitude and phase (2 numbers), based on some preset combination of B_P and B_R Sensors

After: Separate n=1 amplitude and phase from B_R and B_P sensors (4 numbers)

Change 2: Correction Current Request

Before: Single feedback gain and toroidal phase

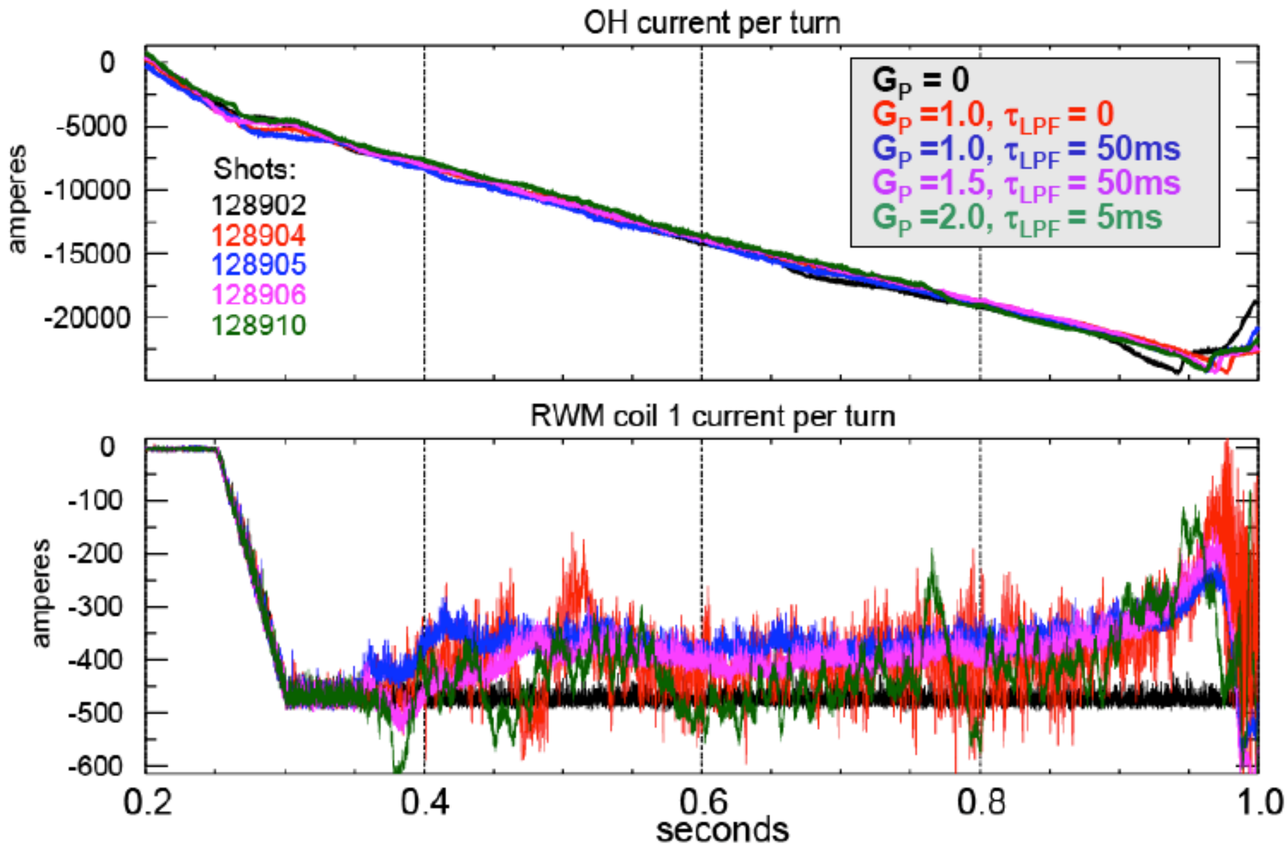
After: i) Separate gain and feedback phase for B_P and B_R mode amplitudes.
ii) Single pole filter on the SPA requests (τ_{LPF}), to remove transients, or to simulate the effect of conducting structures.

n=1 feedback gain, LP filter optimized for I_P= 1.1MA

Expands 2007 data set at 900kA

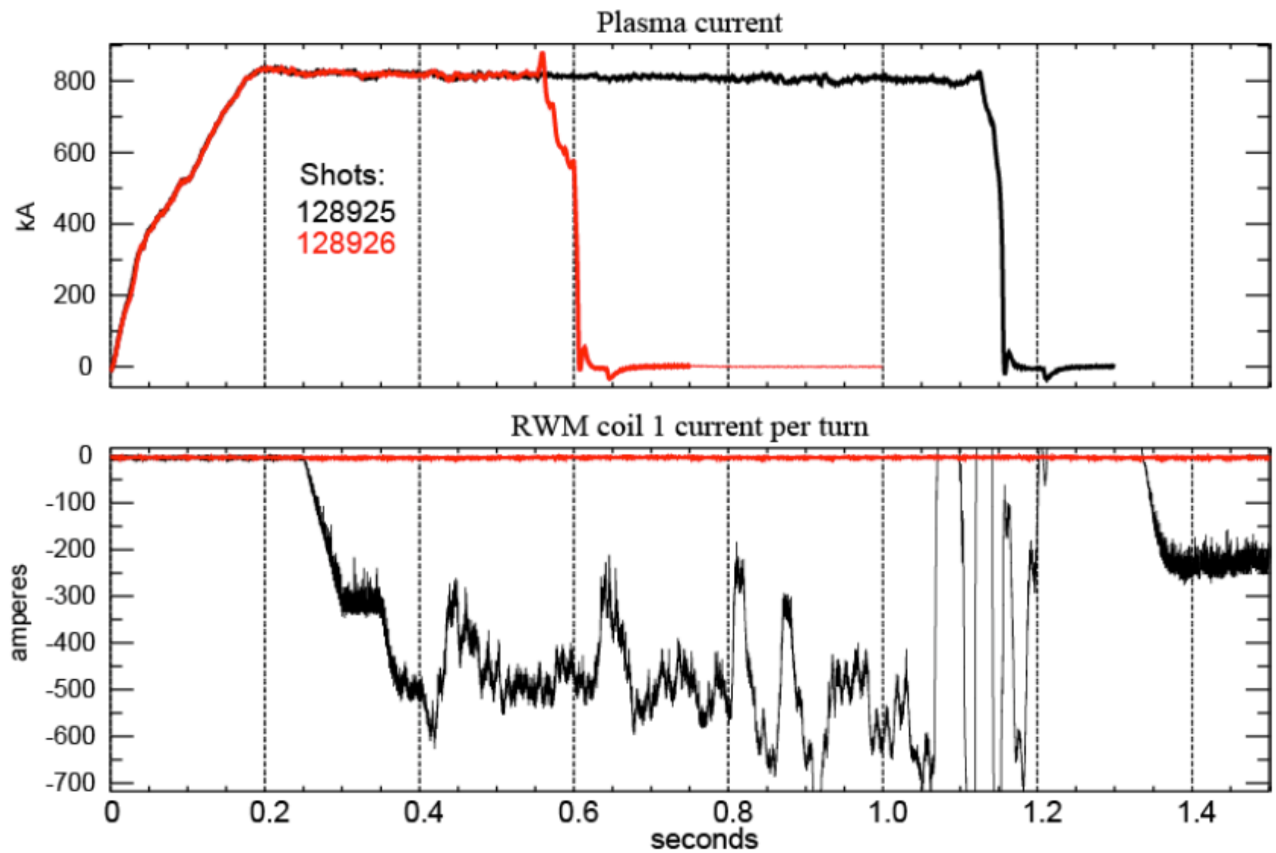
- Instead of applying known n=1 EF, used OHxTF EF (1.1MA uses full OH swing)
- Used B_P U/L averaging from 2007, included n=3 EFC (new for 2008)
- Increased gain scan by factor of 3: 0.7 in 2007 → up to 2 in 2008
  - Response to n=1 RFA from OHxTF error field changes little for G_P > 1
  - System marginally stable at G_P = 2 for τ_{LPF} as low as 1-2ms

→ **Optimal control parameters: G_P = 1-1.5, τ_{LPF} = 2-5ms**



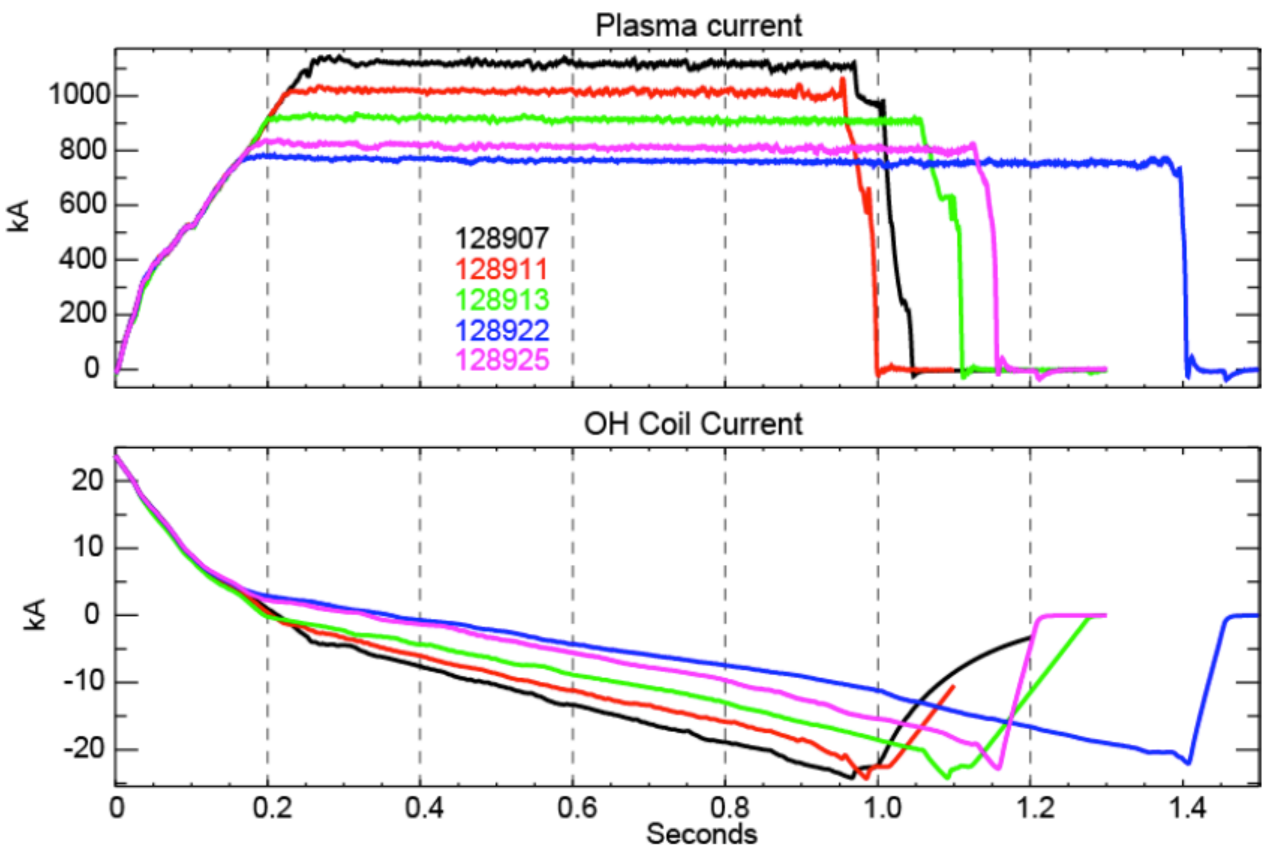
n=3 EFC + n=1 feedback important at lower current (< 900kA) for extending pulse lengths

- Pulses commonly disrupt near ~ 0.6s w/o mode control
  - – 128925: Gain of 2, τ_{LPF}=5 msec
  - – At high beam power (high β_N = 5.5→ 6), mode control insufficient to avoid disruption (not shown)



n=3 EFC + n=1 feedback was successfully applied to wide range of plasma current = 0.75-1.1MA

- Pulses run reliably until nearly all OH flux is consumed



G=2, τ_{LPF}=50 msec
G=2, τ_{LPF}=5 msec
G=2, τ_{LPF}=5 msec
G=2, τ_{LPF}=1 msec
G=2, τ_{LPF}=5 msec

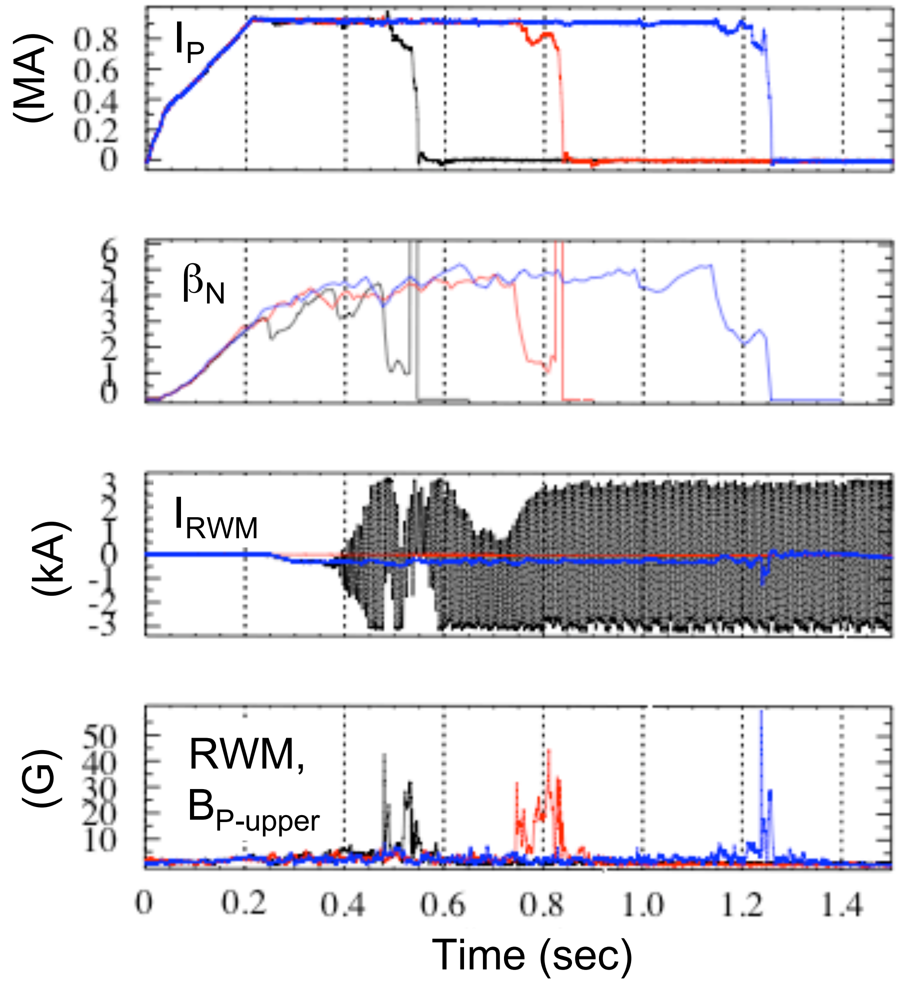
Be Careful…Don't Use Too Much Gain!

Experience From LITER Day 2 Experiments

129070: No EFC, discharge collapses in mid-flattop,

129071: Use settings from XP 823, G=2, $\tau_{SPA\text{-}req}$=.002, big feedback oscillation.

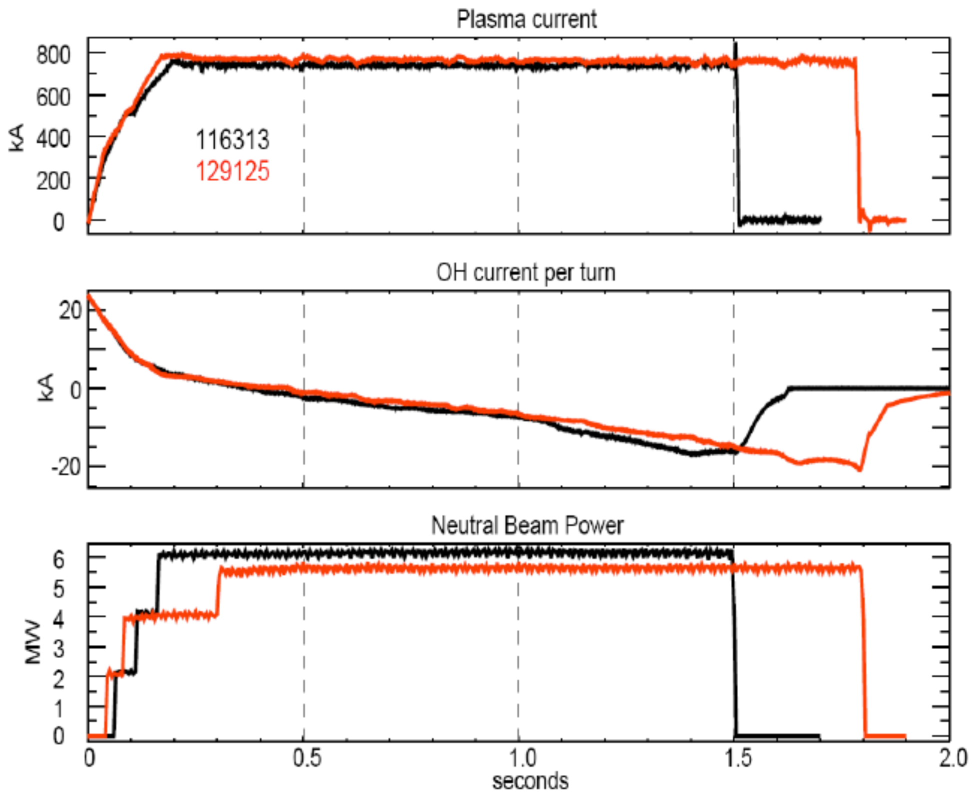
129072: G=0.7, $\tau_{SPA\text{-}req}$=.002, success!



The parameters of 129072 were "locked-in" as the standard pre-programmed n=3 + n=1 DEFC.

Optimized mode control + Lithium → record NSTX pulse-lengths

- Flux consumption reduced following LITER experiments
  - Lower V_{LOOP} at lower P_{NBI}



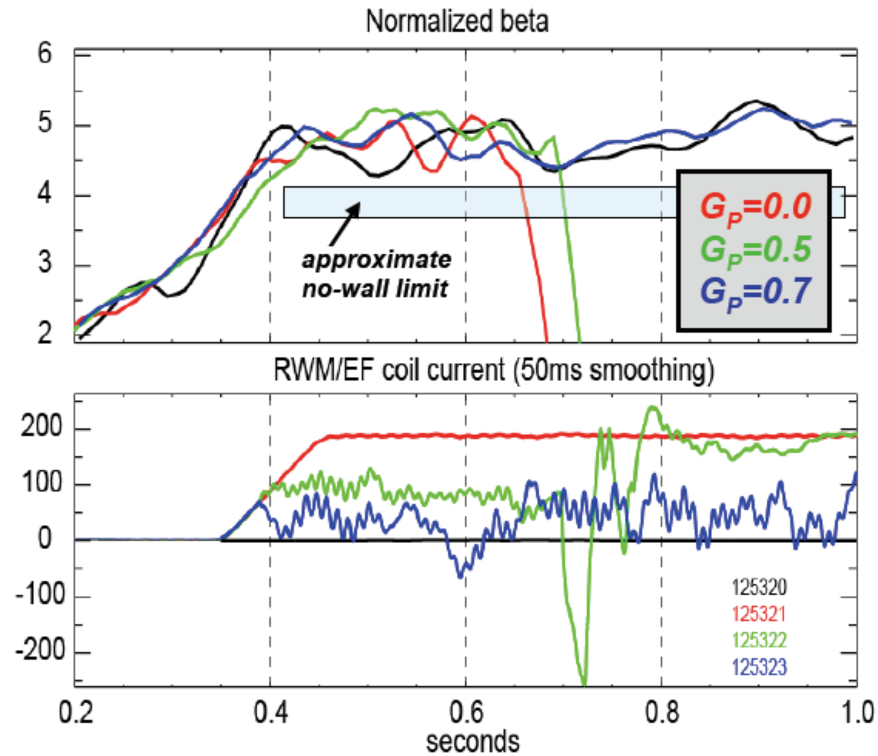
- Li + optimized EFC with (G=1, τ_{LPF}=2 msec) →
  - Avoid late n=1 rotating mode
  - rotation sustained
  - $\beta_N \geq 5$ sustained 3-4 τ_{CR}
  - record pulse-length = 1.8s

Beyond is Backup

RFA suppression algorithm was "Trained" in 2007

- Use Time With Minimal Intrinsic EF.
- Apply n=1 EF to reduce rotation, destabilize RWM.
- Find corrective feedback phase that reduces applied EF currents.
- Increase gain until applied EF currents are nearly completely nulled and stability restored.

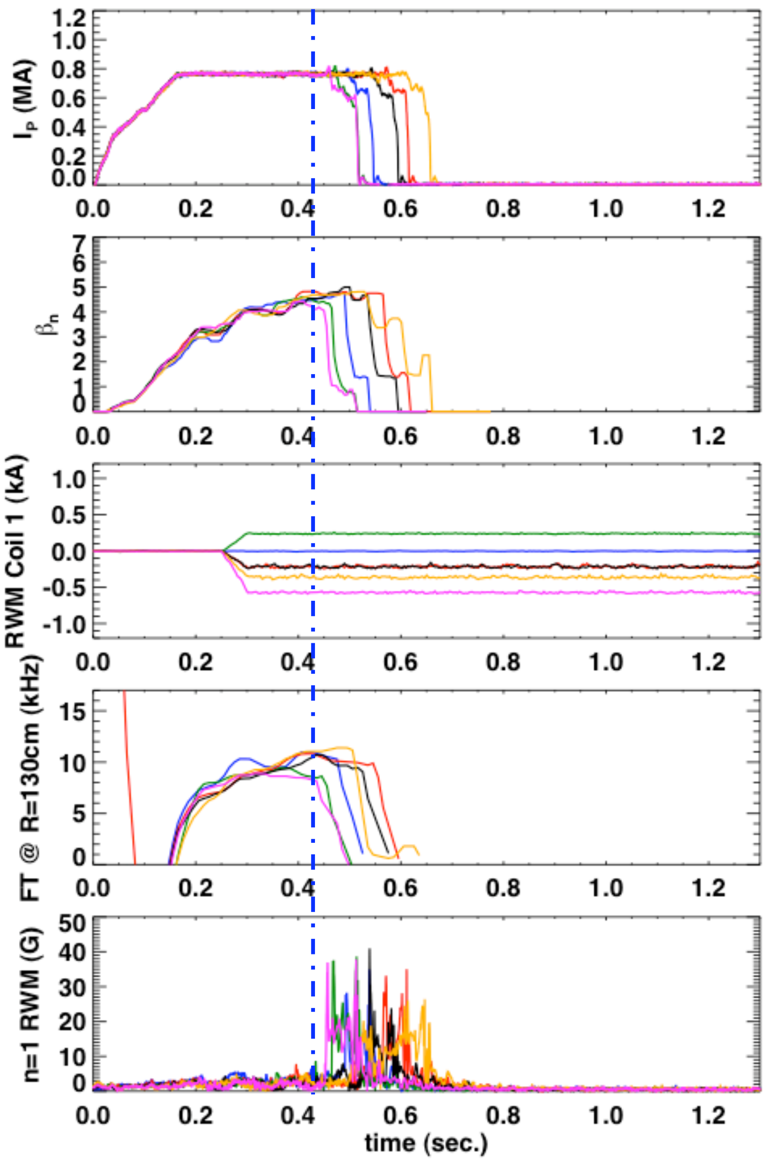
Turn off applied field, and utilize optimized setting for RFA and RWM feedback.



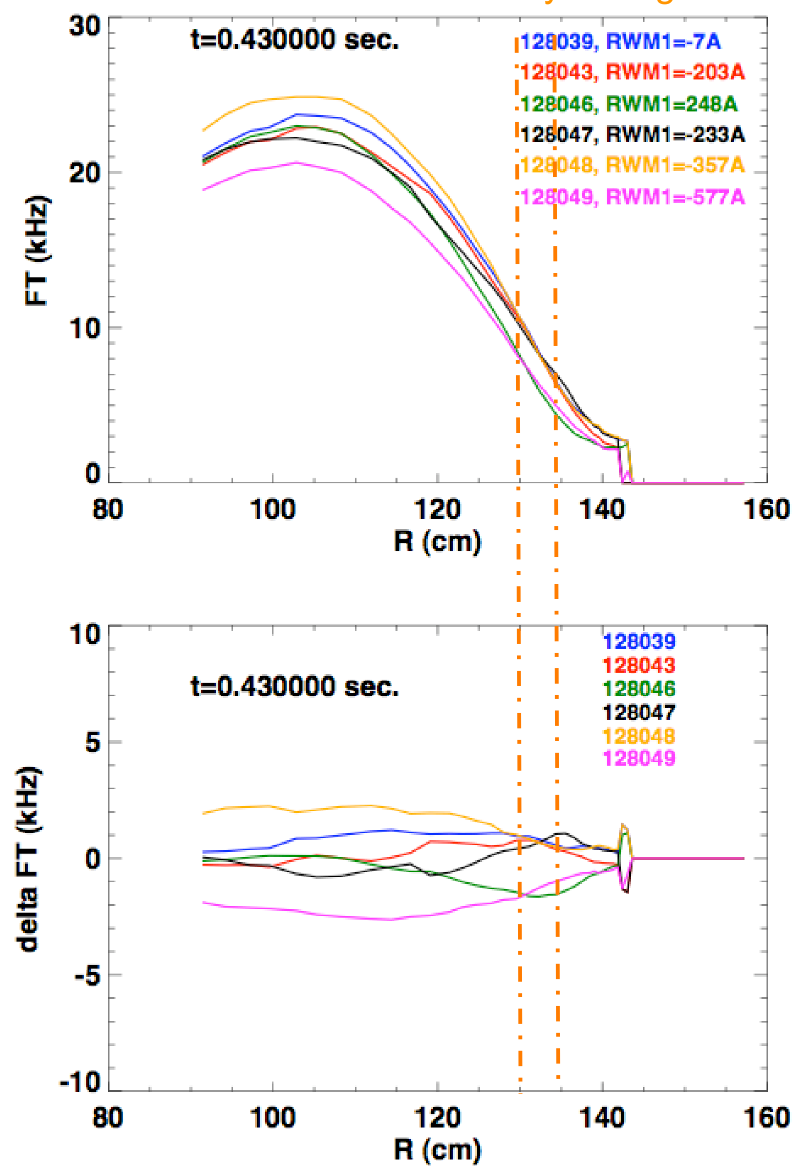
Final "Optimal" Configuration
Use identification of the mode form B_P sensors
Use a feedback phase of ???°
Use a feedback gain of 0.7

Case 1: 750 kA in XP 823 (I).

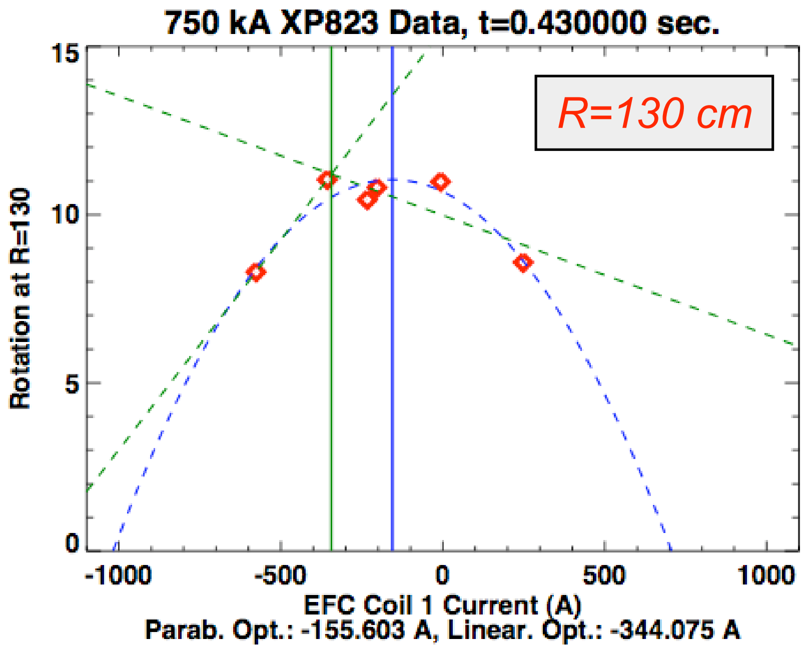
Consider Time Denoted By Blue Line

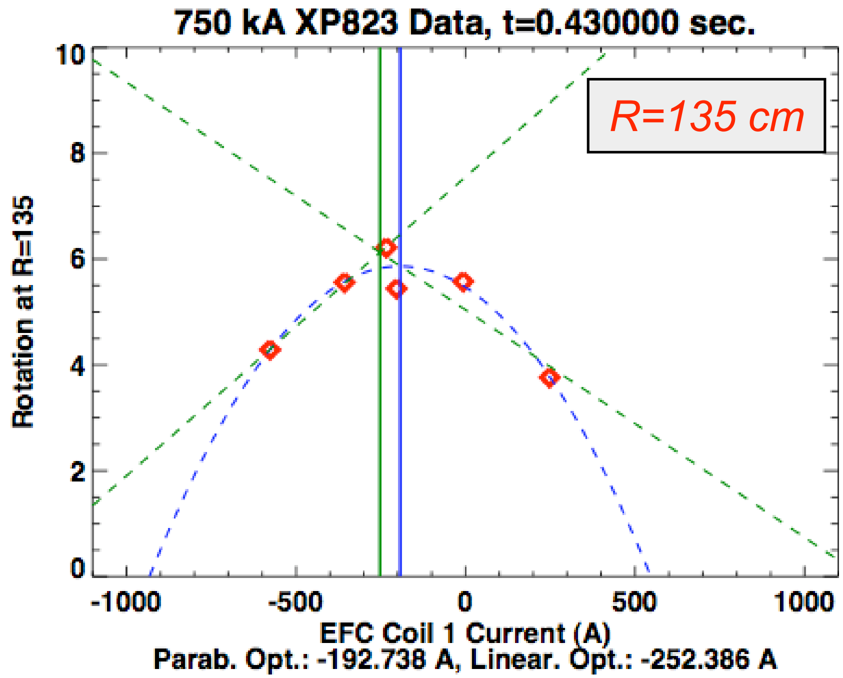


Consider Radii Denoted By Orange Line



Case 1: 750 kA in XP 823 (II).



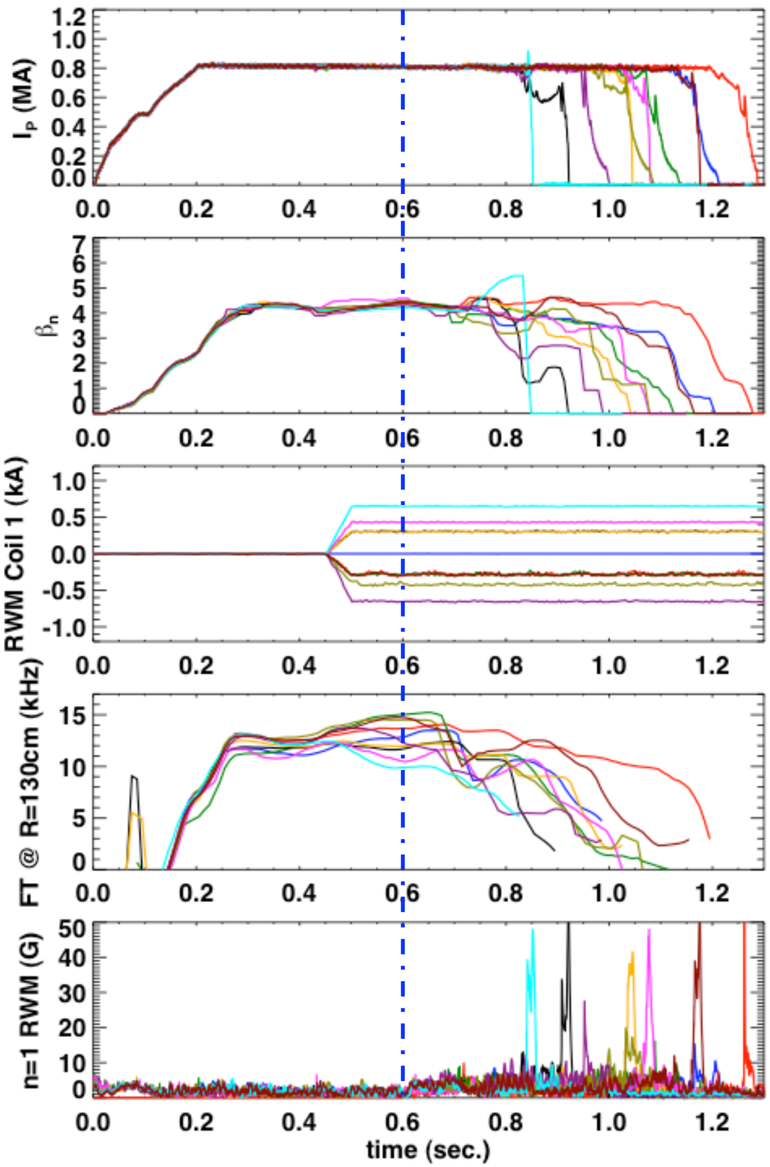


Parabolic Optimization:150-200
Linear Optimization: 250-350

Parabolic Function Seems Like a Reasonable Choice

Case 2: 900 kA in XP 701 (I).

Consider Time Denoted By Blue Line



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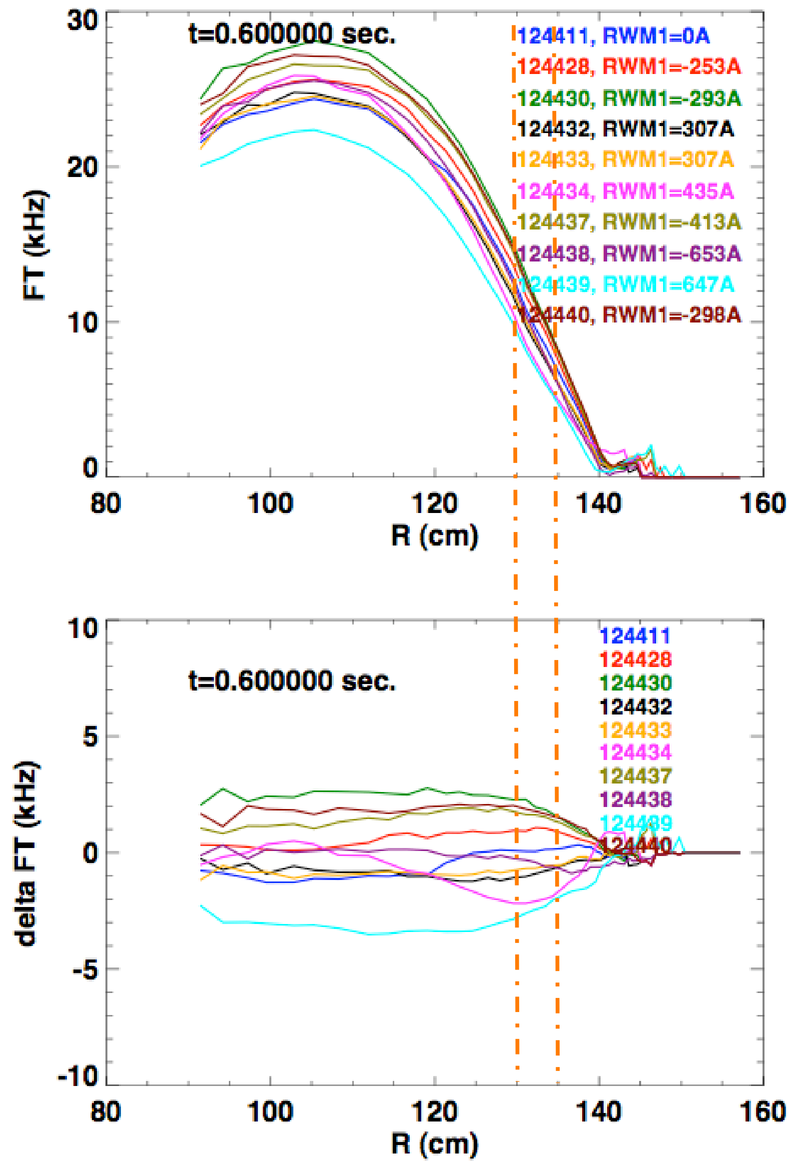
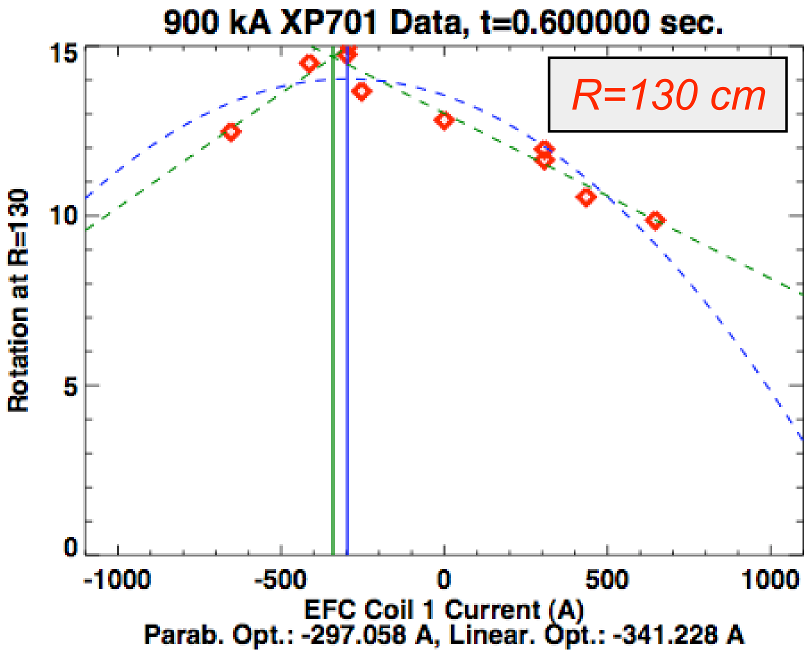
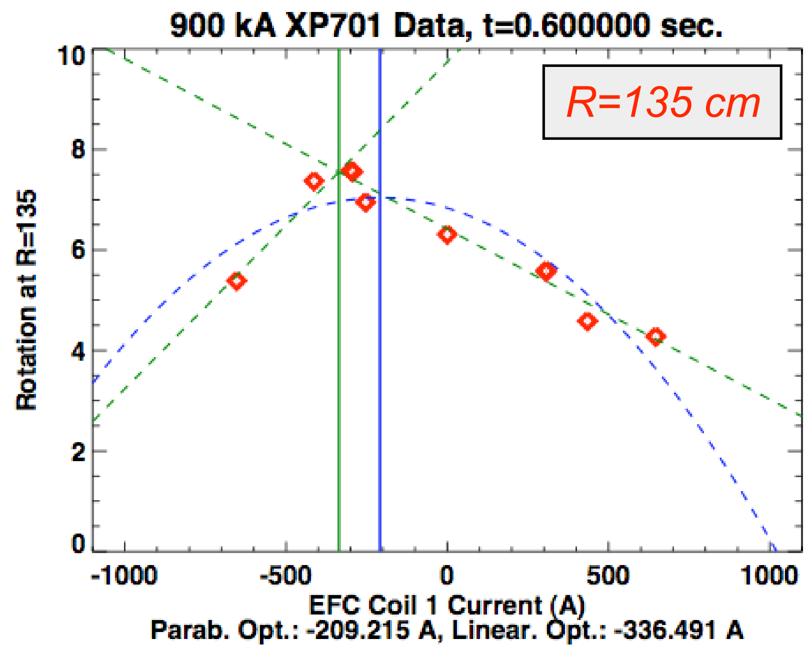


Case 2: 900 kA in XP 701 (II).





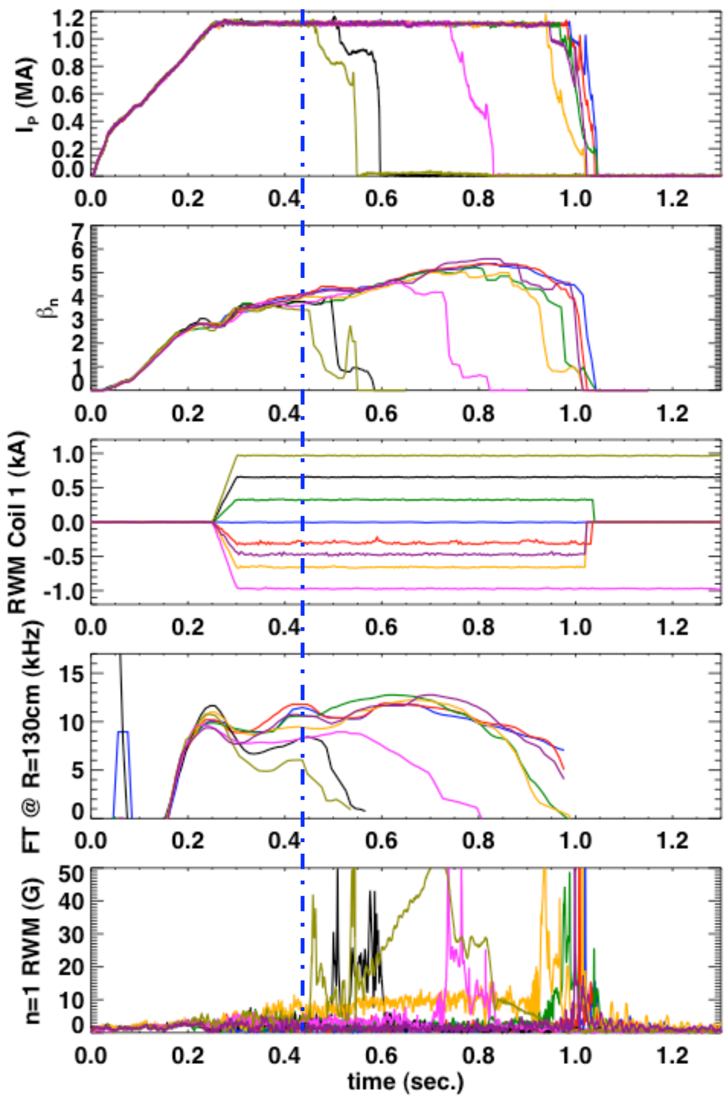
Parabolic Optimization: 200-300

Linear Optimization: ~340

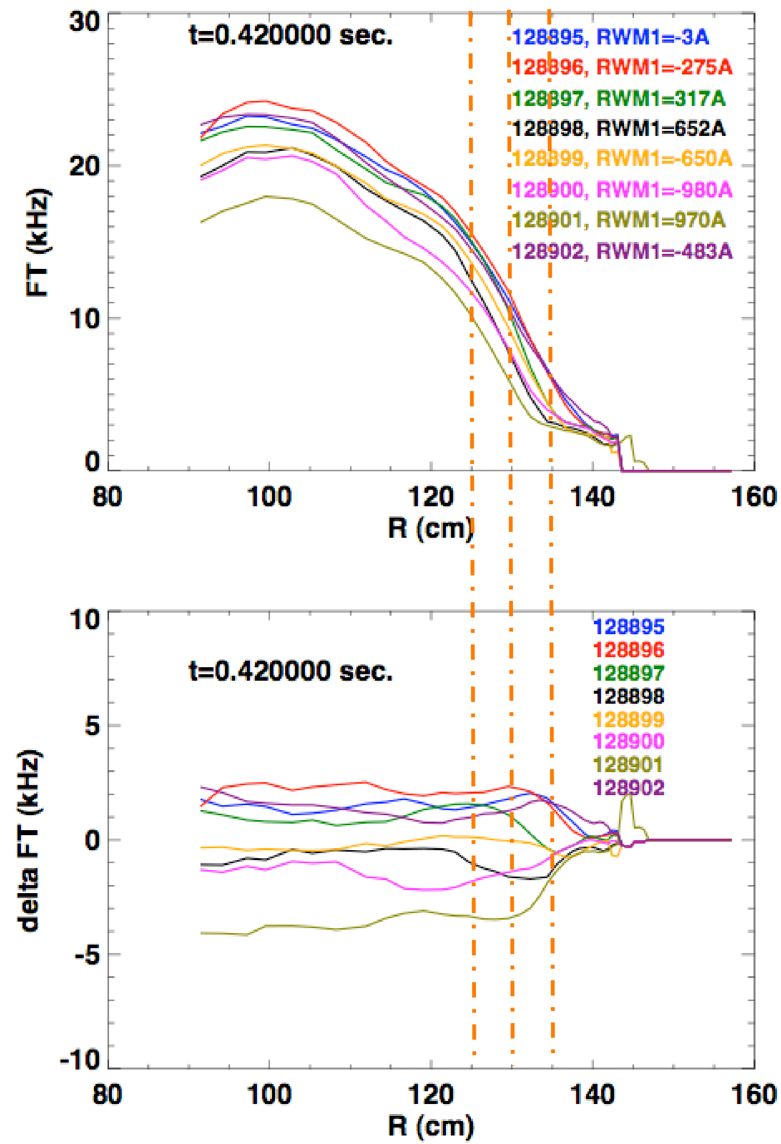
Linear Intersections Seems to Capture the Trend Better

Case 3: 1100 kA in XP 823 (I).

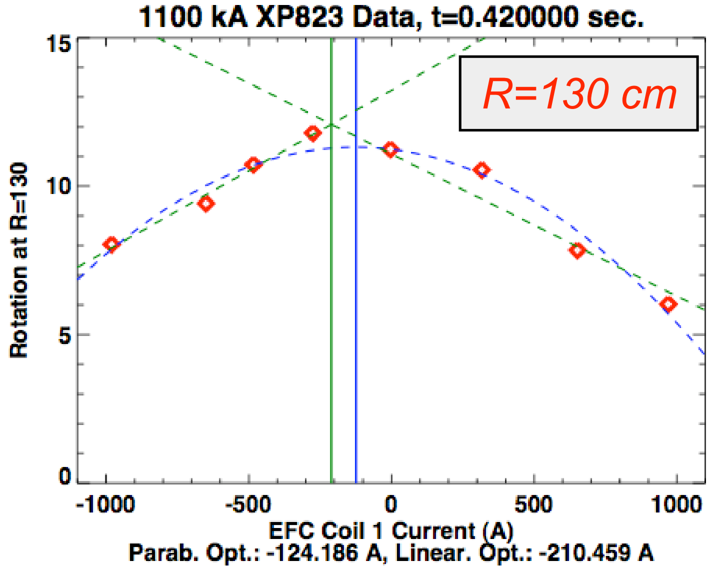
Consider Time Denoted By Blue Line

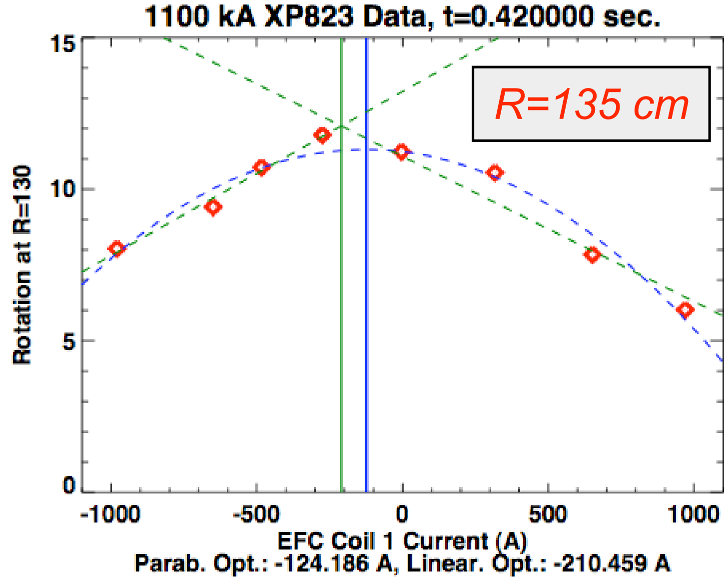


Consider Radii Denoted By Orange Lines



Case 3: 1100 kA in XP 823 (II)





Parabolic Optimization: 100-130
Linear Optimization: ~200

Parabolic Function Seems Like a Reasonable Choice