Detection of and Correction of n=2 & 3 Error Fields in NSTX

Experimental Results from the 2007 & 2008 Campaign

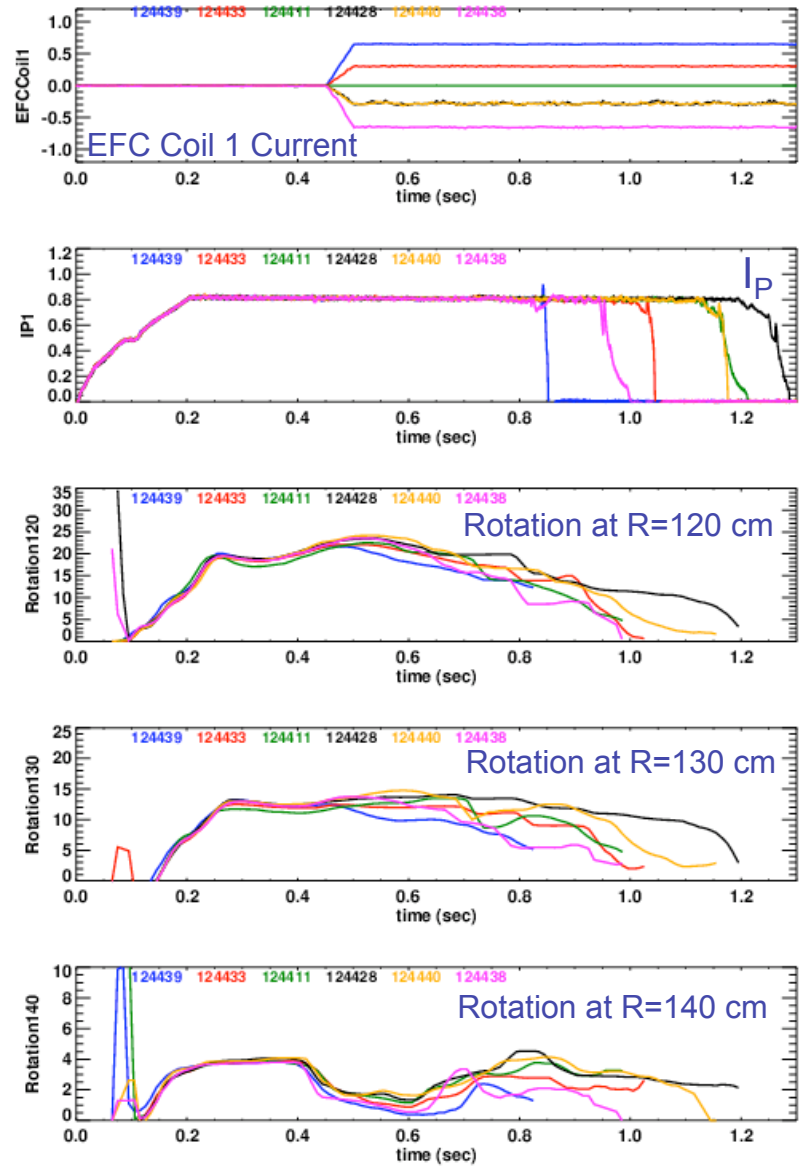
- n=3 error fields exist (XP701 & XP823)
  - Their correction improves performance.
  - The source of the required correction remains illusive.
- n=2 error fields, if present, are small (XP805)

Stefan Gerhardt, July 2008

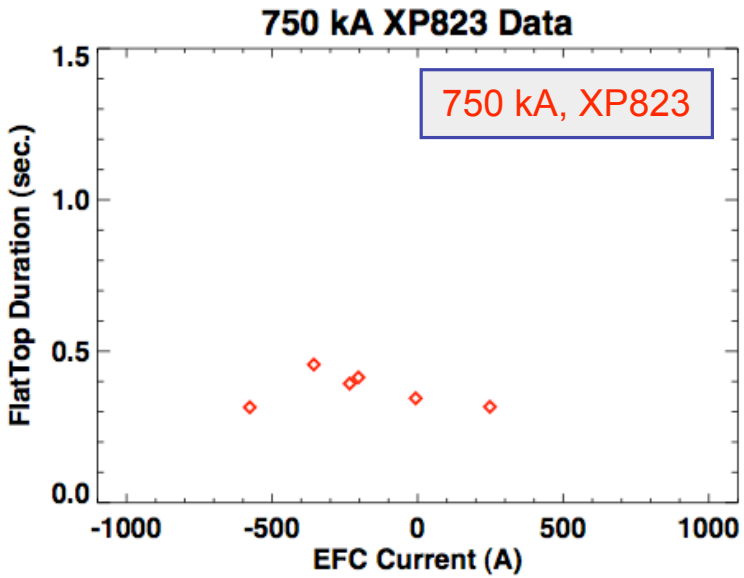
n=3 Applied Fields can Improve Discharge Performance

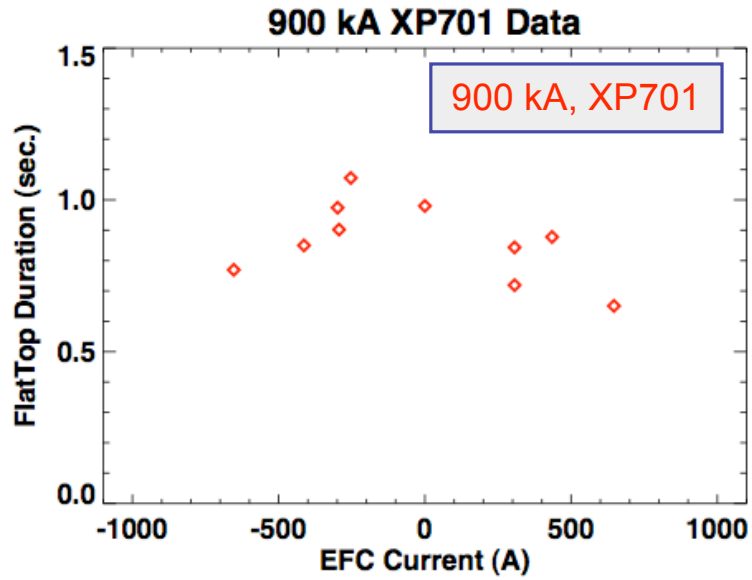
- Impact on rotation appears as soon as n=3 field is turned on.
  - Some signs of n=3 cause acceleration, others braking→*there is an intrinsic n=3 error field*.
- Pulse length improves with the n=3 polarity yielding maximum rotation.

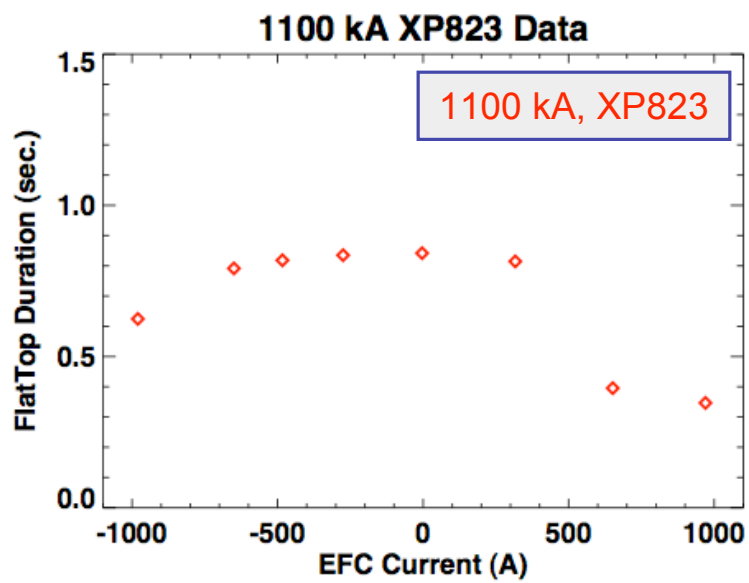
What determines the required n=3 correction level?
The plasma current?
The PF 5 coil?
The TF coil?



Pulse Length is Not A Reliable Guide For the Optimal Correction







- Shots with a wide variety of n=3 levels at 1100kA ran out the OH.
- Lots of scatter in the XP701 data.
- Timing of the RWM has inherent jitter.

Use Rotation as the Metric

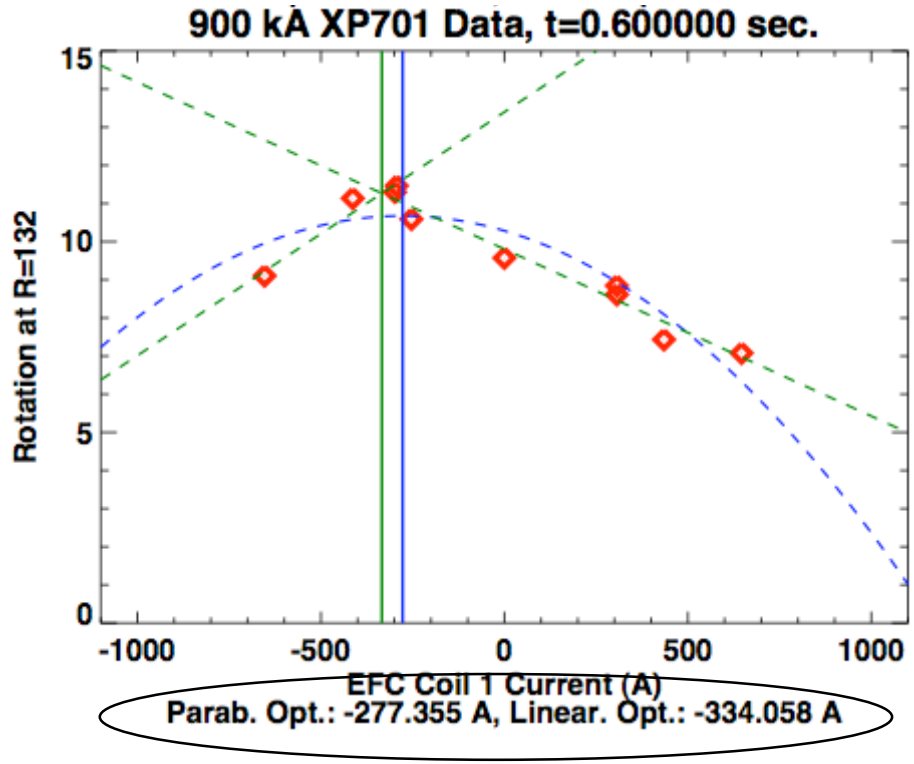
Method Utilized to Determine the n=3 Correction

- 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

<u>Intersection Method (green)</u>

- More Biased Toward the Maximum Single Point
  - *Typically Yields Higher Correction Currents*

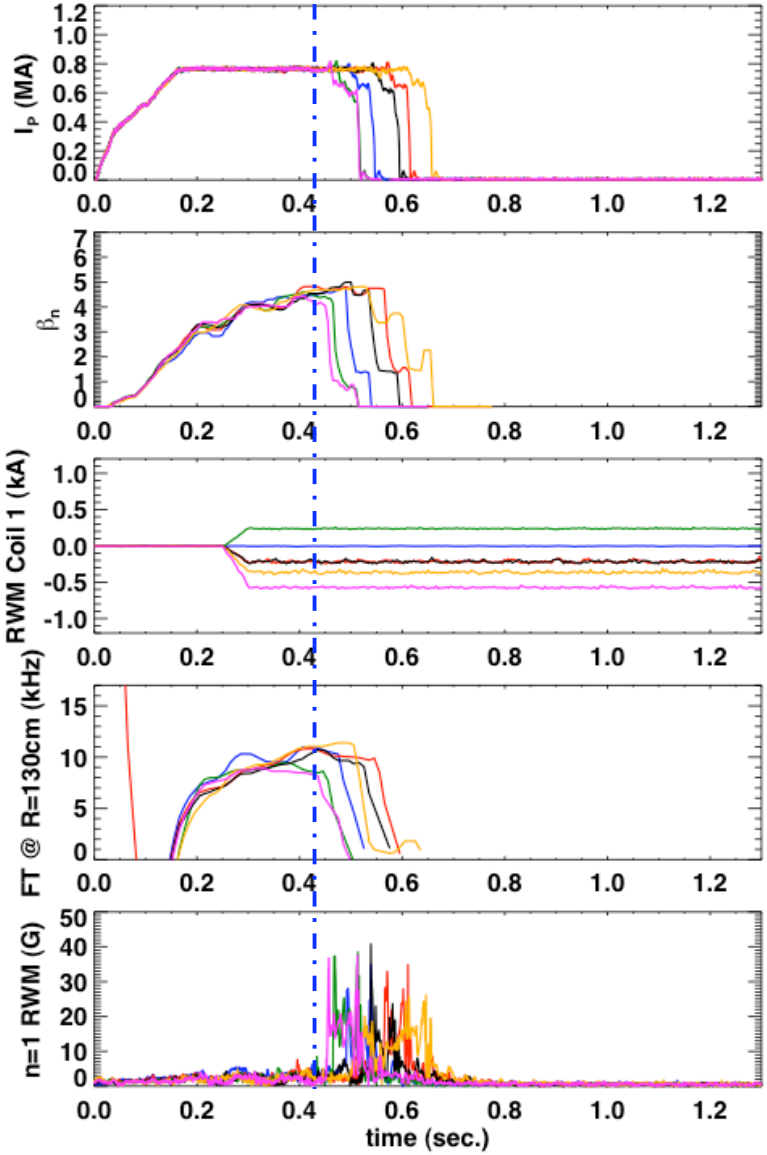
Shots Used in Analysis For Optimal n=3 Correction

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

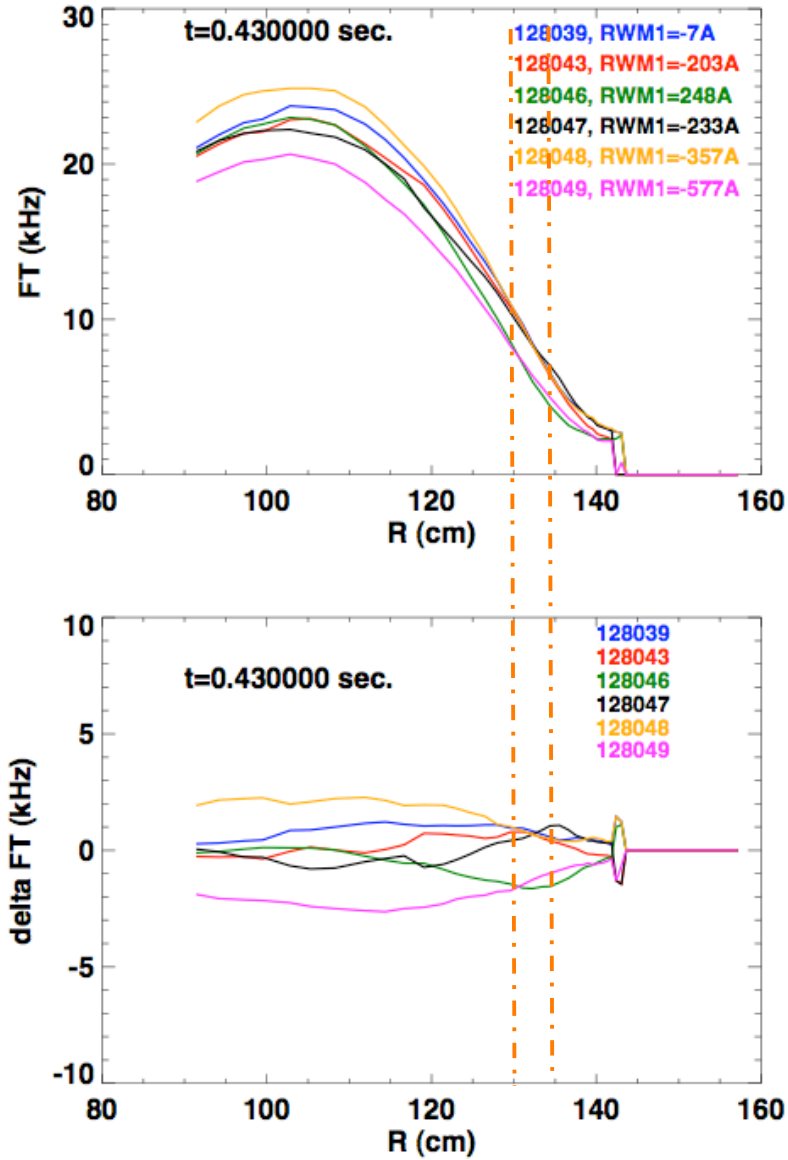
- Shots span two years.
- No n=1 DEFC or RWM feedback in any of these.
- XP701 data used gap-control algorithm, XP823 used Isoflux.

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

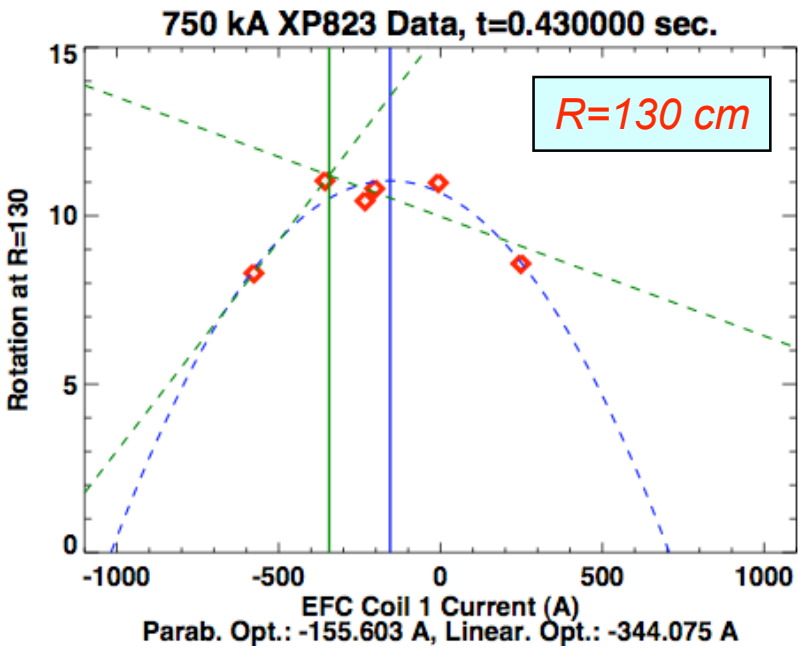
Consider Time Denoted By Blue Line

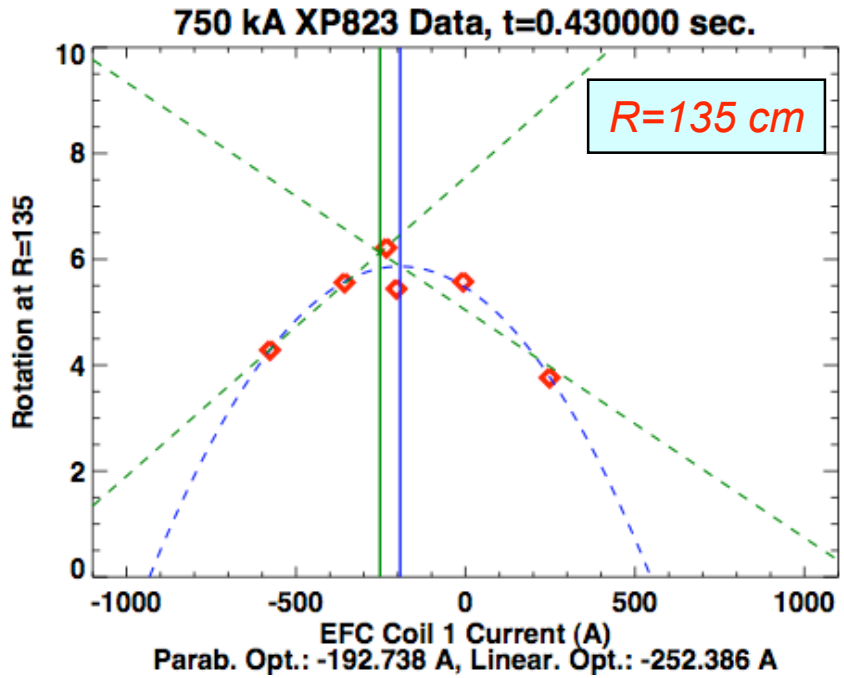


Consider Radii Denoted By Orange Line



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



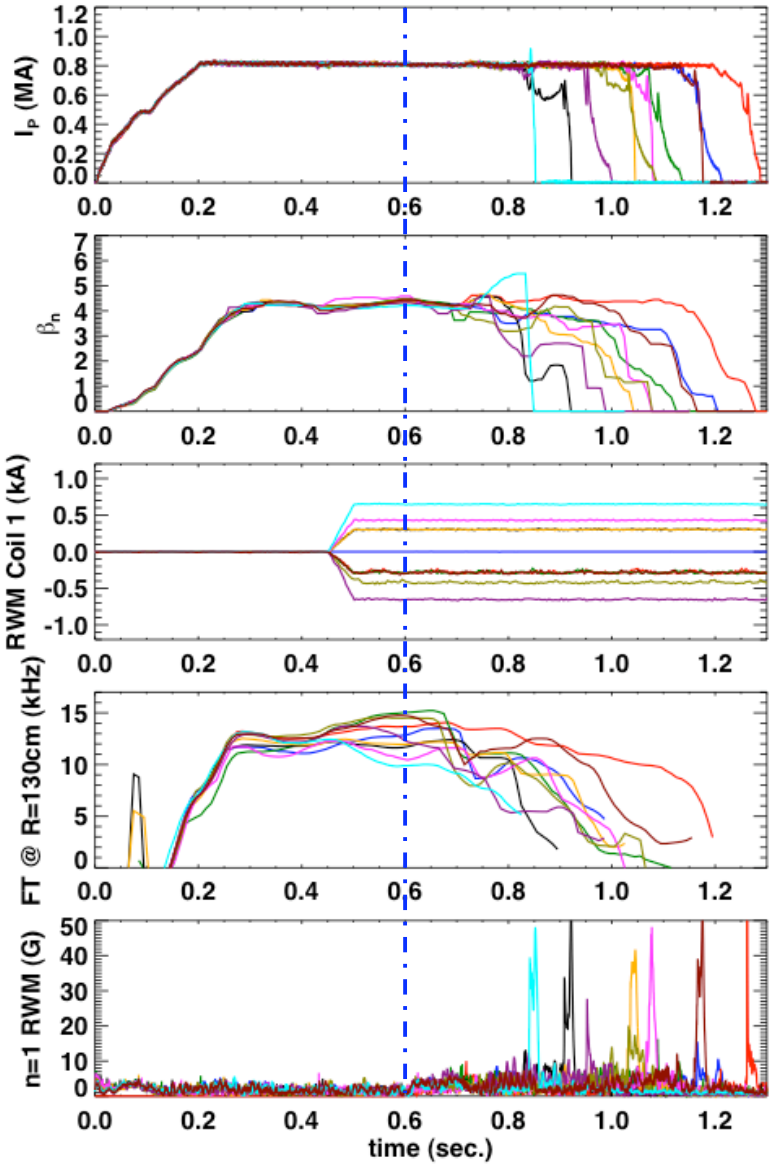


Parabolic Optimization:150-200
Linear Optimization: 250-350

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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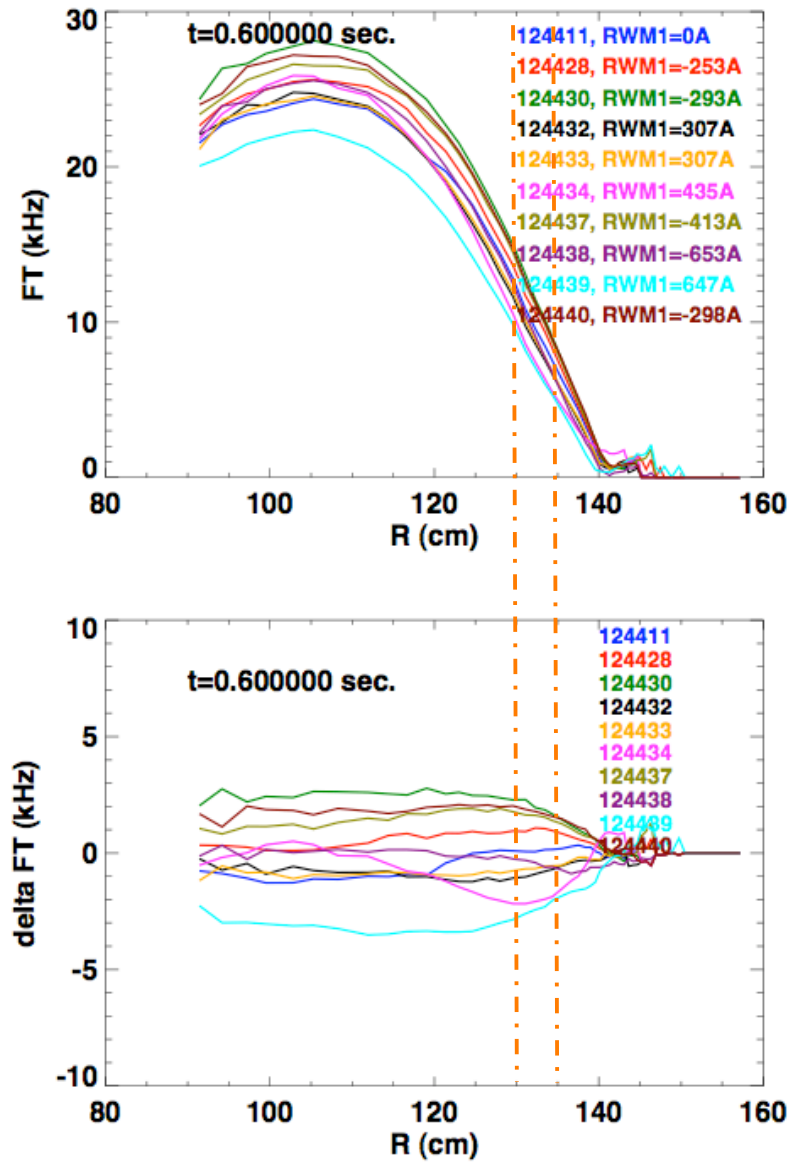
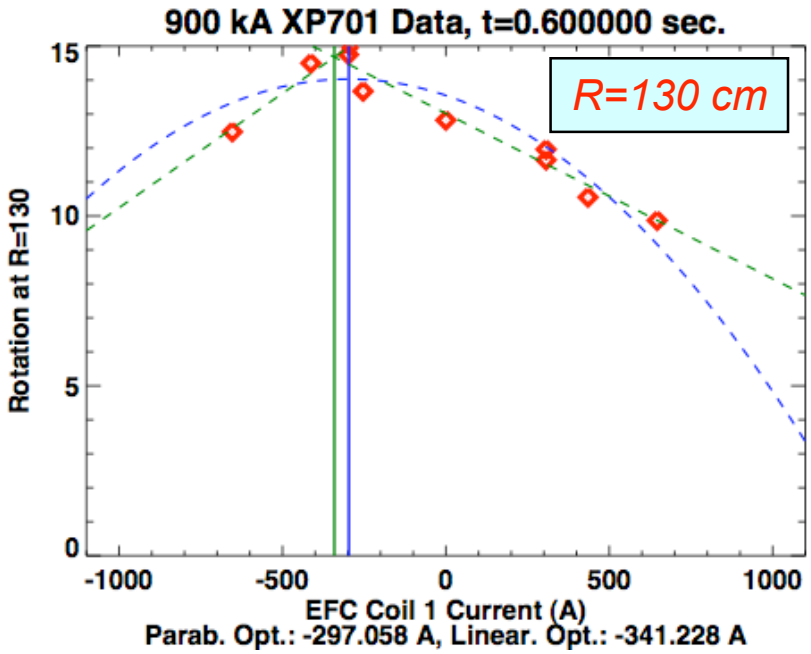
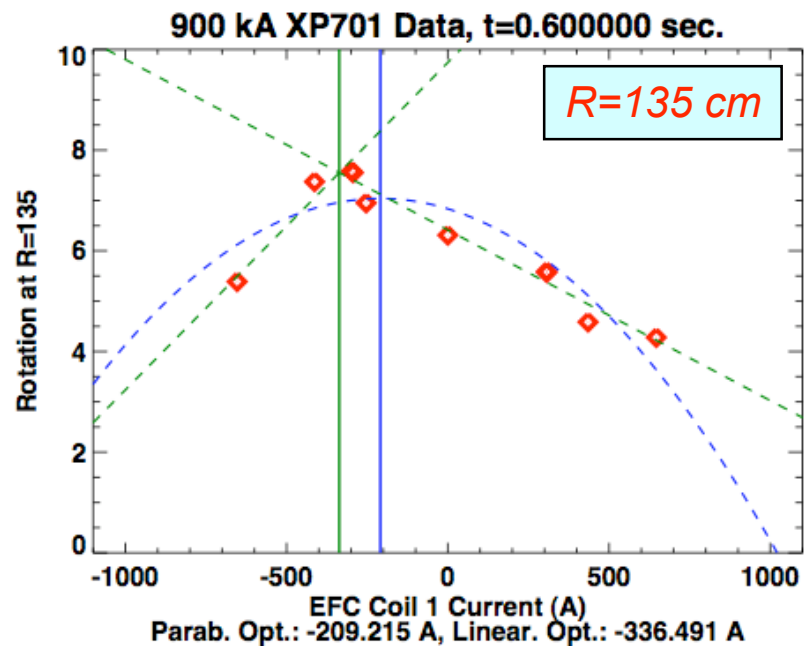


Case 2: 900 kA in XP 701 (II).



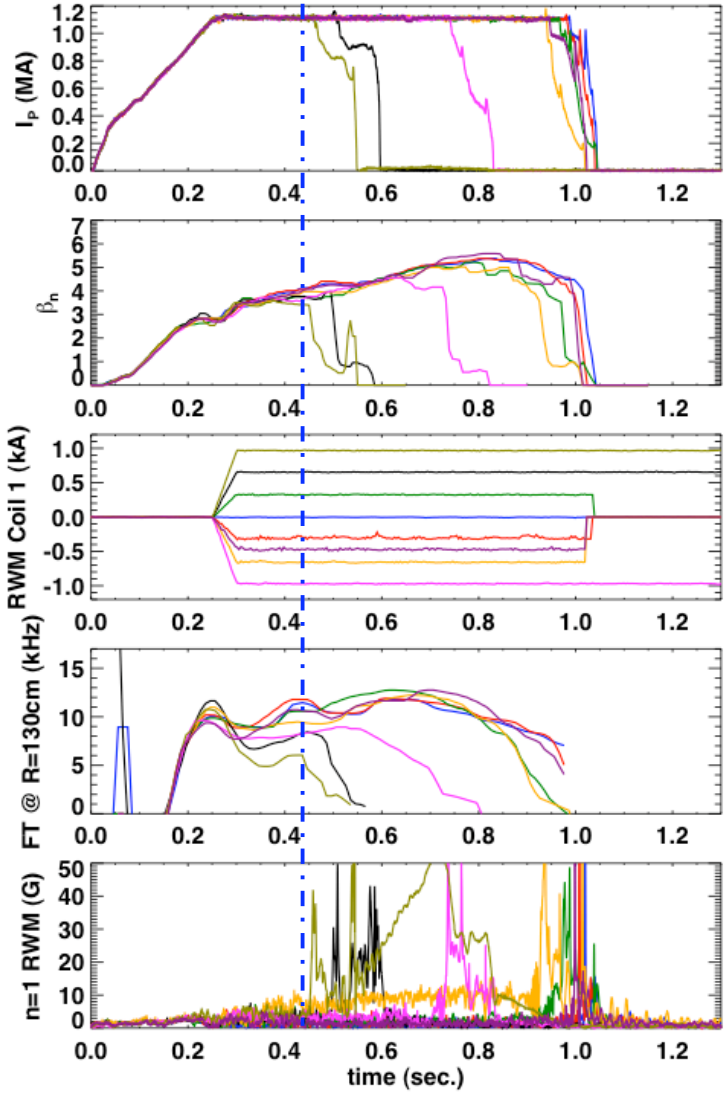


Parabolic Optimization: 200-300
Linear Optimization: ~340

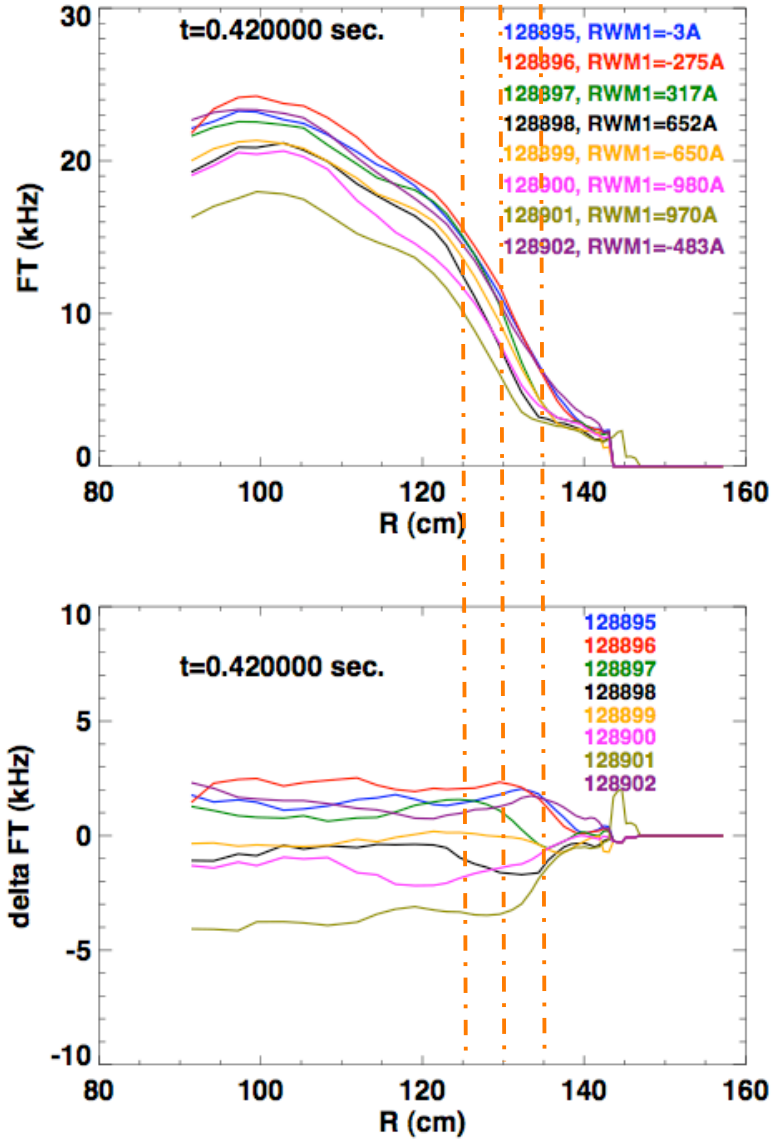
Linear Intersections Seems to Capture the Trend Better

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

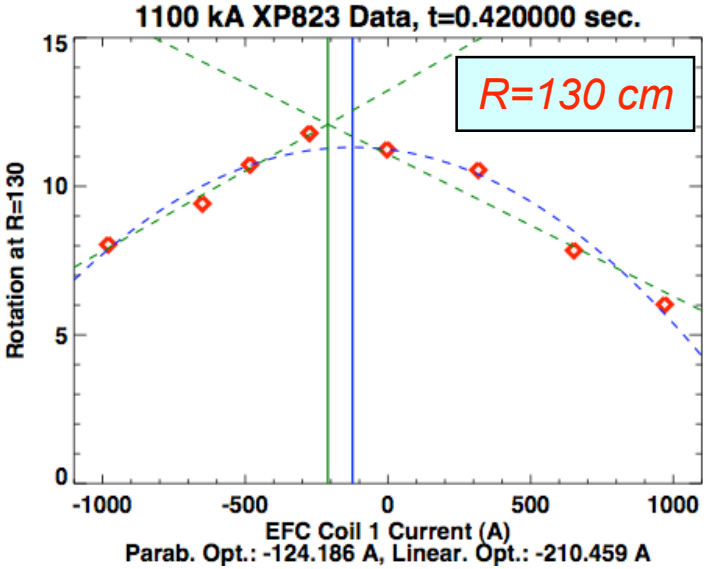
Consider Time Denoted By Blue Line

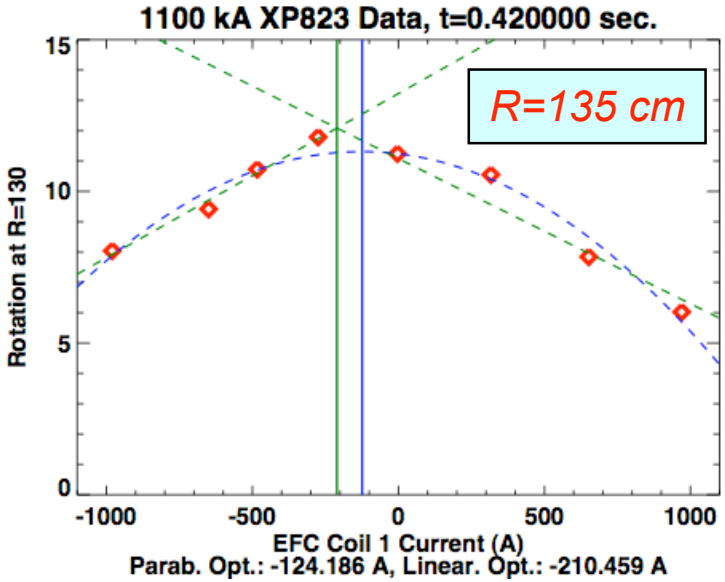


Consider Radii Denoted By Orange Lines



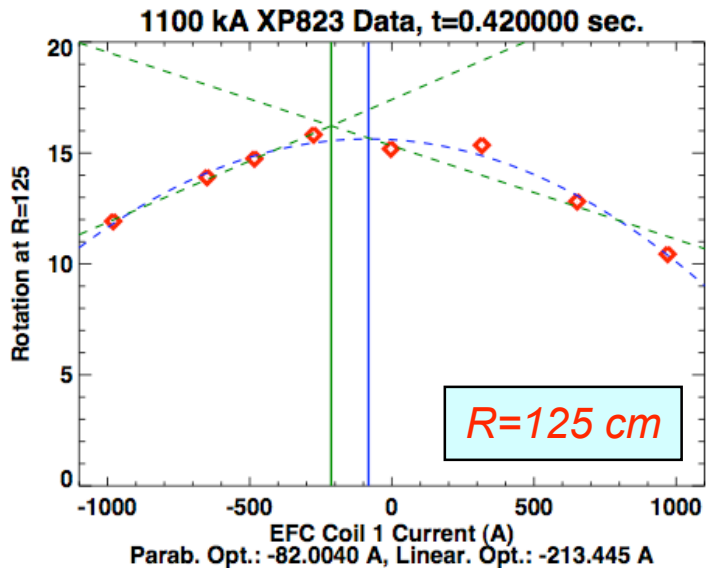
Case 3: 1100 kA in XP 823 (II)





Parabolic Optimization: 100-130
Linear Optimization: ~200

Parabolic Function Seems Like a Reasonable Choice



Pull it all Together…No Clear Trends

I_P	PF 5 Current	Typical Correction From Parabolic Fits	Typical Correction From Linear Intersections	Recommended Correction (by SPG)
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 corrections 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.*

XP805 Used the Same Technique to Study n=2 Intrinsic Error Fields*

1: Create a reproducible target plasma

- *Should have an RWM in mid-discharge.*

2: Apply n=2 fields of various magnitudes and phase.

3: Look for improved performance:

- *Increased Rotation Staves of Instability, Leading to…*
- *Longer Pulse Length*

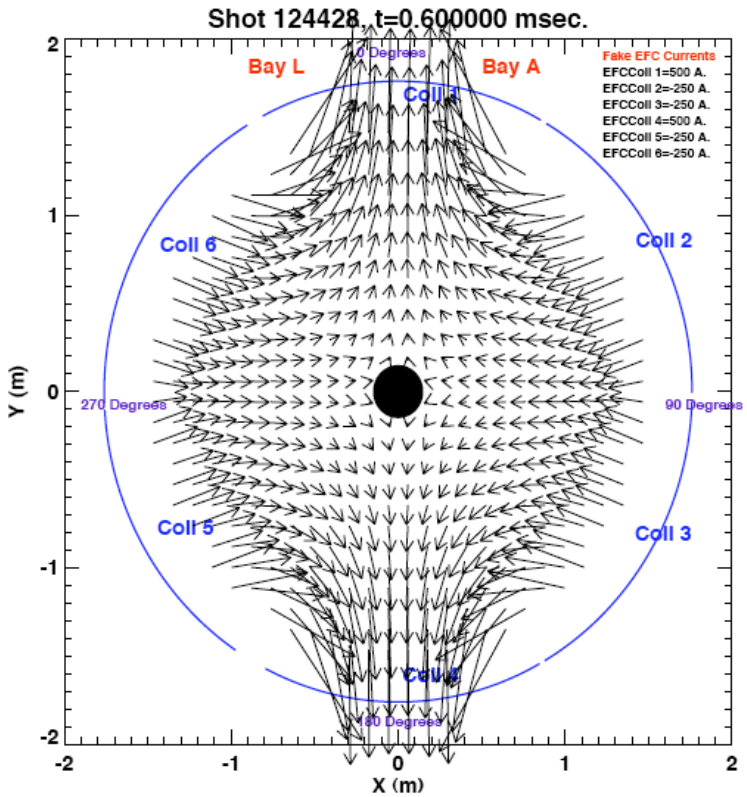
4: If n=2 fields improve performance, then optimize amplitude and phase.

Side Benefit: Generate RWMs with n=2 braking

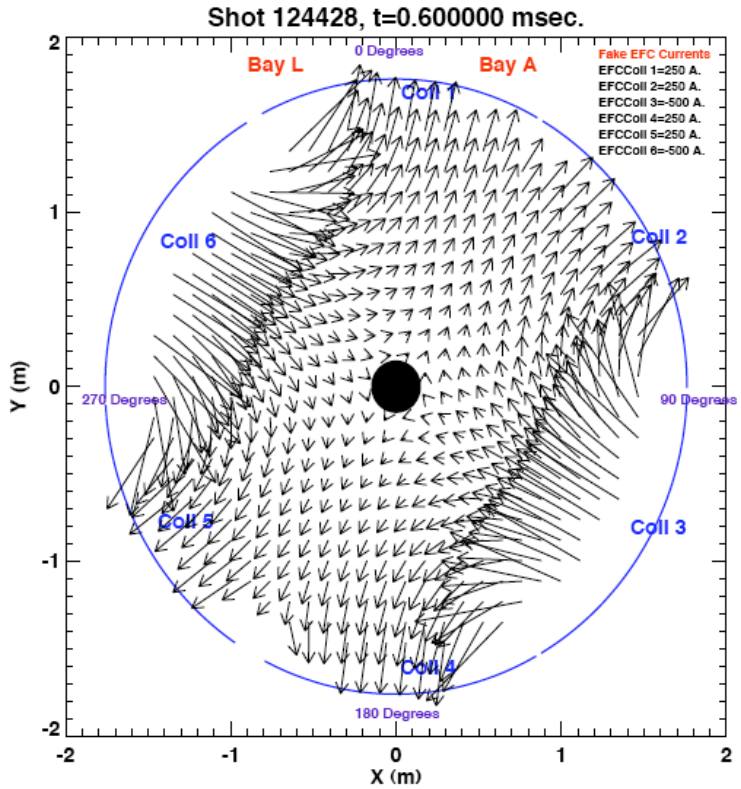
**S. P. Gerhardt, J.E. Menard, J. Berkery*

Need a Sign Convention for n=2 Fields

0° Configuration



30° Configuration



Convention Leads to the Following Coil and SPA Currents

Mapping of SPA Units To Coil Pairs

SPA	Coils
1	-3,-6
2	-1,-4
3	-2,-5

- Positive Coil Field Points Out of the Vessel
- Positive SPA Current Leaves the Positive Terminal

Mapping of n=2 Phase to Coil And SPA Currents

Phase	Coil1	Coil 2	Coil 3	Coil 4	Coil 5	Coil 6	SPA1	SPA2	SPA 3
0	1	-1/2	-1/2	1	-1/2	-1/2	1/2	-1	1/2
30	1/2	1/2	-1	1/2	1/2	-1	1	-1/2	-1/2
60	-1/2	1	-1/2	-1/2	1	-1/2	1/2	1/2	-1
90	-1	1/2	1/2	1	1/2	1/2	-1/2	1	-1/2
120	-1/2	-1/2	1	-1/2	-1/2	1	-1	1/2	1/2
150	1/2	-1	1/2	1/2	-1	1/2	-1/2	-1/2	1

XP805 Day 2 Shot List

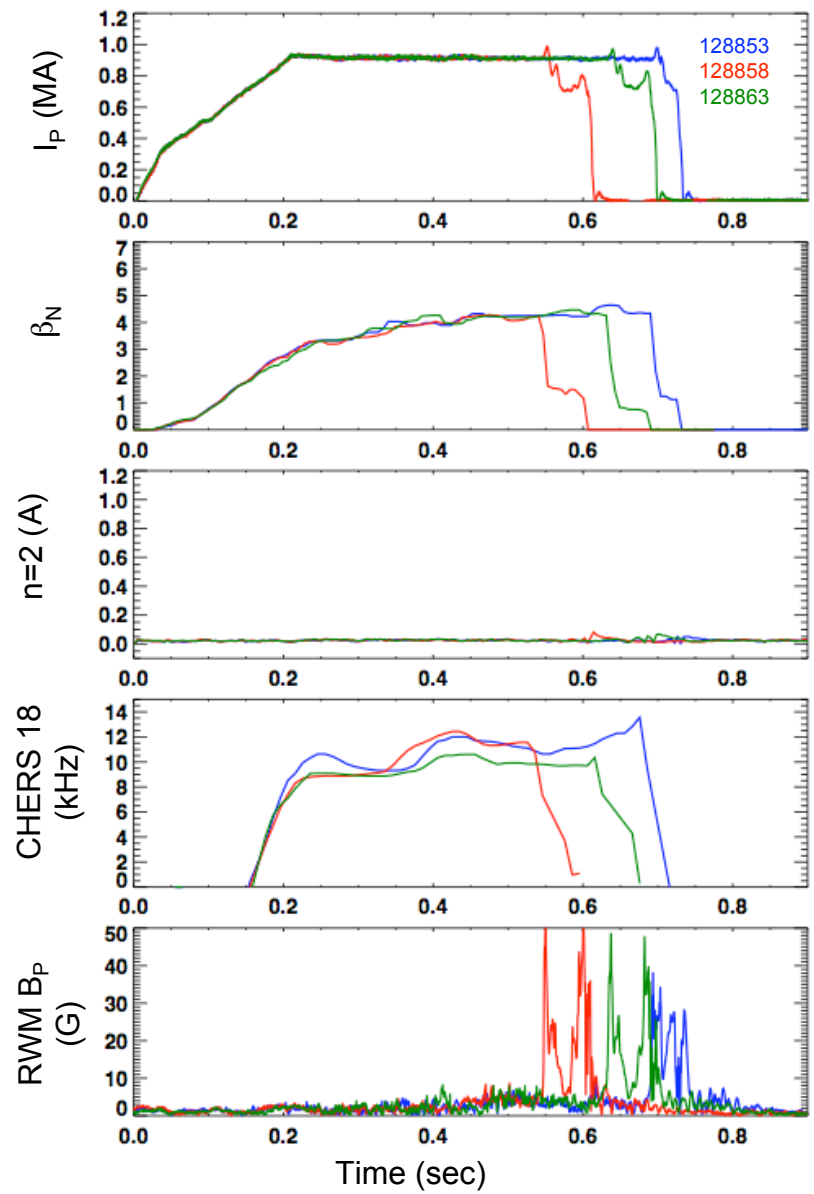
Shot	n=2 Amplitude	n=2 Phase	Note
128852	0	NA	Fiducial
128853	0	NA	
128855	500	120	
128856	500	30	
128857	500	60	Very long, repeated below to verify that it is a fluke
128858	0	NA	Reference Shot
128859	500	150	
128860	500	0	
128861	500	90	
128862	500	60	Repeat of 128857, short
128863	0	NA	Reference Shot
128864	1000	60	
128865	1000	150	
128866	1000	0	
128867	1000	90	
128868	1000	120	No CHERS
128869	1000	30	No CHERS
128870	500	60	Repeat of 128857, short, No CHERS

3 Reference Shots Demonstrated Reliable Target Through the Day

- Three reference shots distributed through scan.
- All three showed "RWM" at intermediate rotation values.
- Range of "healthy" discharge durations:

$$0.575 < t_{RWM} < 0.7$$

Now Apply n=2 Fields and Look For Faster Rotation, Longer Pulse Lengths!



First Scan Utilized 500 A

Did 500A of n=2 help…no.

No cases lasted longer than the reference discharges.

Rotation slower than in the reference discharges (see in two slides)

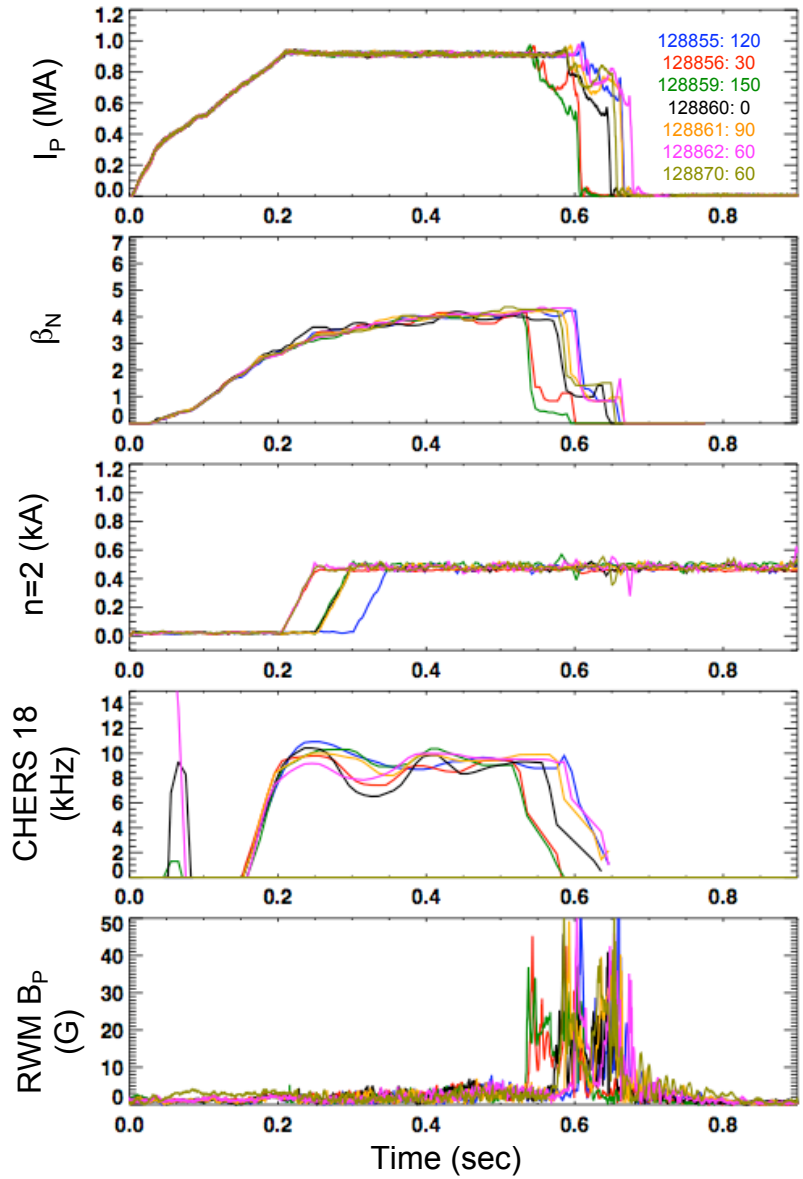
Why? Either…

n=2 EFs are smaller (and we don't care),

or

n=2 EFs are bigger (and we *really* care)

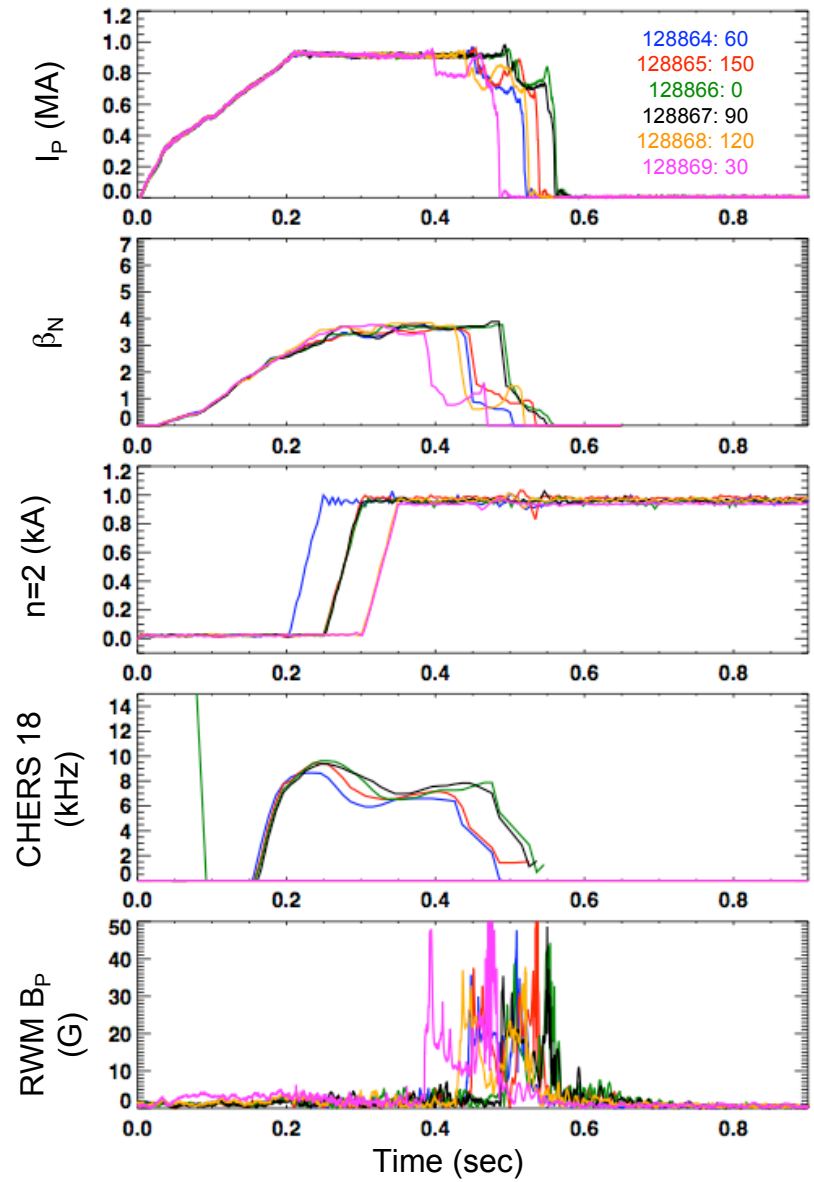
Repeat the Scan With Larger n=2 Fields



1000 A of n=2 Only Shortened the Discharges

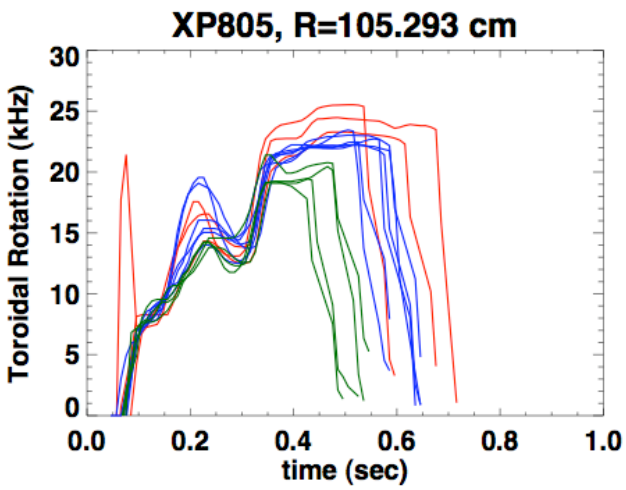
Did 1000A of n=2 help…no?

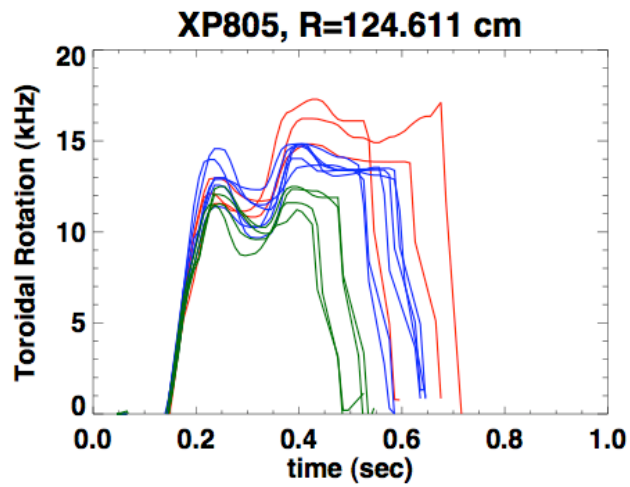
Shot duration was dramatically shortened.
Rotation substantially slower.

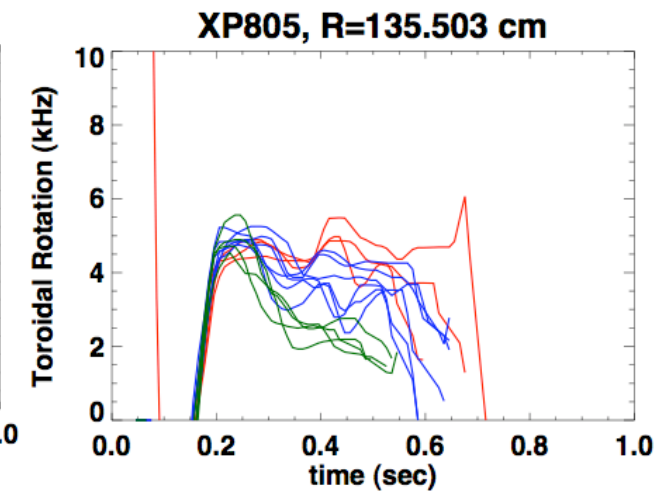


Rotation Is Always Slower with Applied n=2 Fields

Monotonic Decrease in Rotation with Applied n=2 Fields

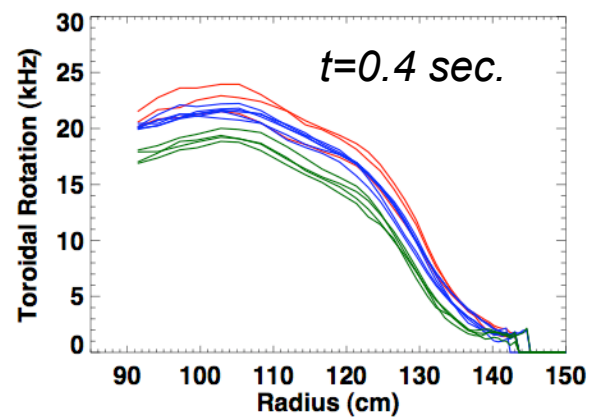






Color Code
3 Reference Shots
7 Shots with 500 A n=2
4 Shots with 1000A n=2

Decrease Occurs Across the Entire Profile →



Summary: n=2 fields

n=2 error fields, if present, are sufficiently small that correcting them does not yield performance benefits.

Discharge duration is not improved, and often degraded, by application of n=2 fields.

Rotation across the entire profile is reduced by application of n=2 fields.

This is "good" news…no need for n=2 correction!