# XP 805, n=2 Intrinsic Error Fields and RWM Critical Rotation in NSTX

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# Overview Of XP 805

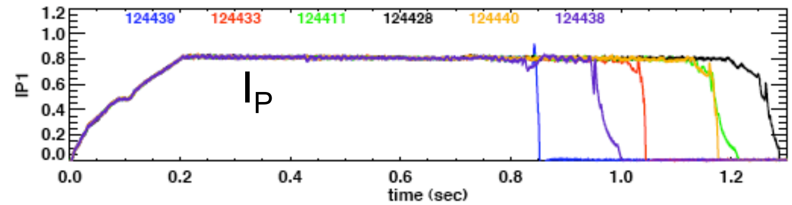
- Previous XPs found asymmetric plasma response to an n=3 applied field → implies n=3 EF
- Look for asymmetric response to n=2 and optimize correction
  - Look for asymmetric response to n=2 applied fields → *determine direction for optimal correction*.
  - Optimize the magnitude of n=2 EFC in direction of optimal correction → *optimize for longest pulse and determine if n=2 EF strongly impacts performance*.

- Use braking for RWM critical rotation frequency
  - Overcompensate the n=2 correction until rotation collapse occurs → *look at RWM critical rotation profile with n=2 braking.*
  - Using optimized n=2 correction, apply n=6 perturbation. Increase perturbation until rotation collapse & RWM occur. → *look at RWM critical rotation profile with n=6 braking.*

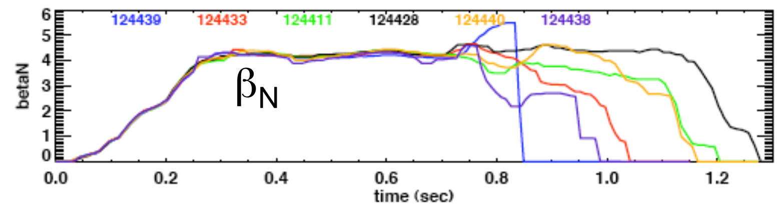
*• Compare n=2 & 6 braking to results from n=3 braking (NSTX), n=1 braking (DIII-D), and balanced injection (DIII-D).*
*• n>1 typically ignored in present tokamaks, including ITER*

# XP 701 Showed Asymmetric Response to an n=3 Error Field (I)

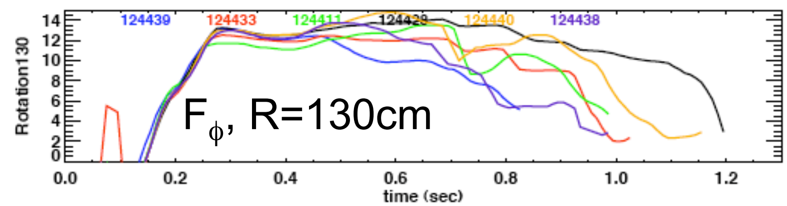
$I_p$: Pulse Length Changes
Depending on n=3 correction



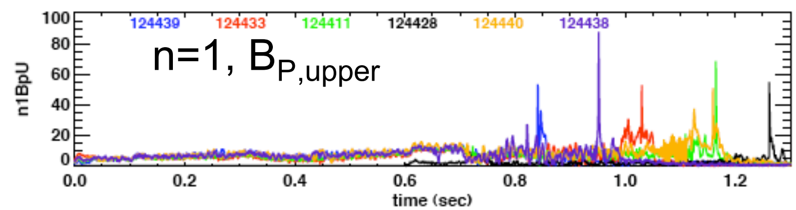

Beta-N collapse
Proceeds Disruption



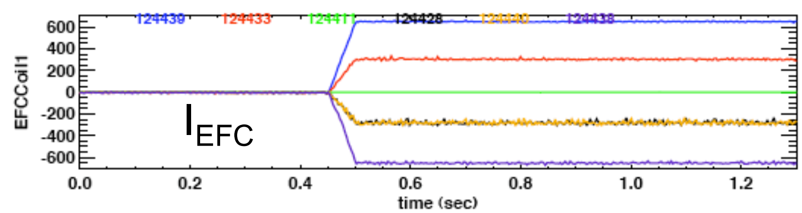

Toroidal Rotation @ 130cm
sustained with optimal correction




Mode detected in $B_P$ sensors at
time of collapse-> RWM



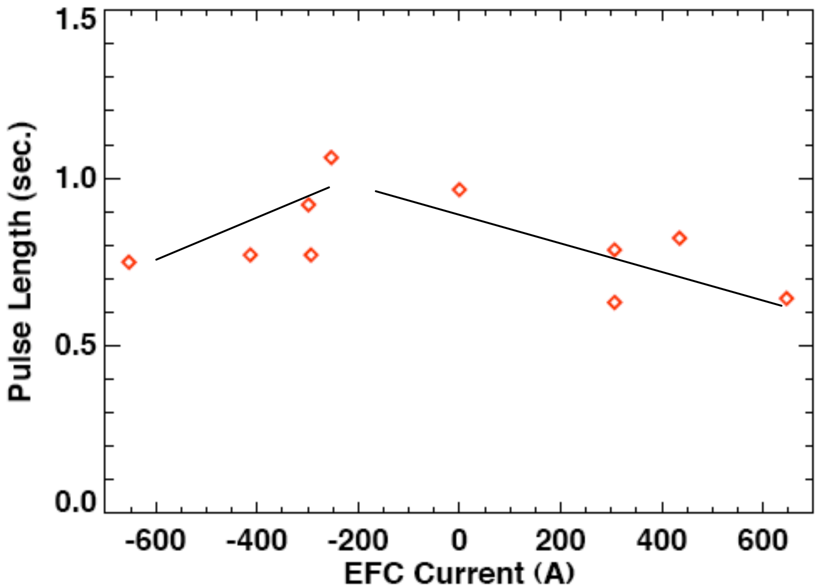

EFC Coil Currents from -600A
to 600A

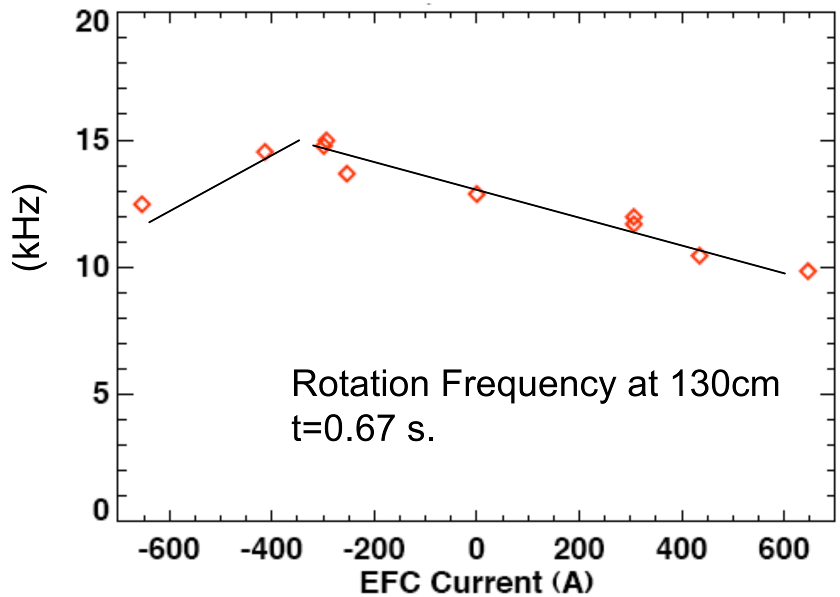


# XP 701 Showed Asymmetric Response to an n=3 Error Field (II)

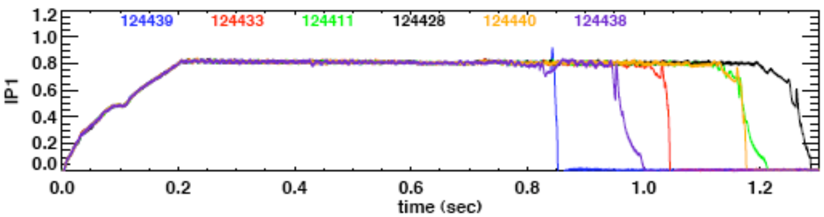
*Pulse Length is Optimized For ~-300 A of SPA Current*

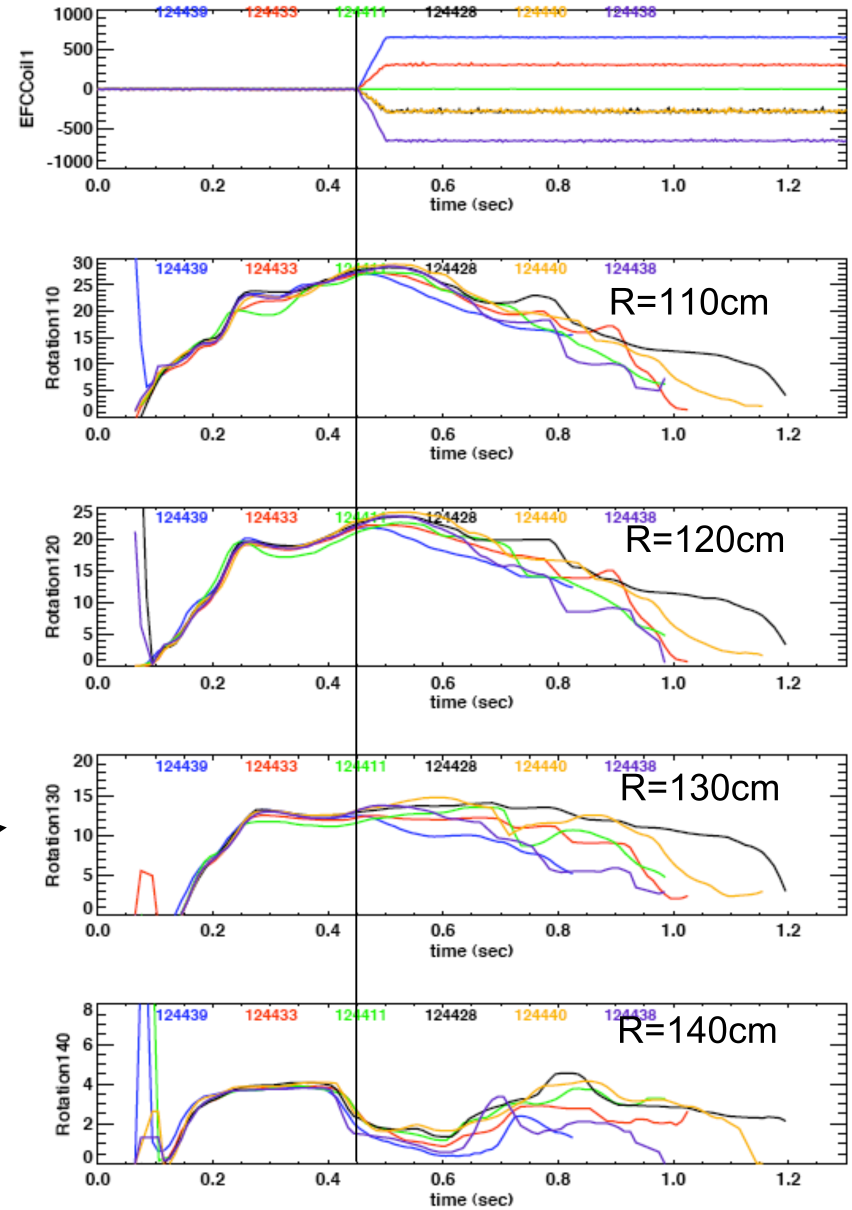
*Edge Rotation is Maximized For ~-300 A of SPA Current*



# Edge Rotation Showed The Strongest Response




Core rotation decays in a similar way in all shots.

Rotation in outer part is better sustained with correction,

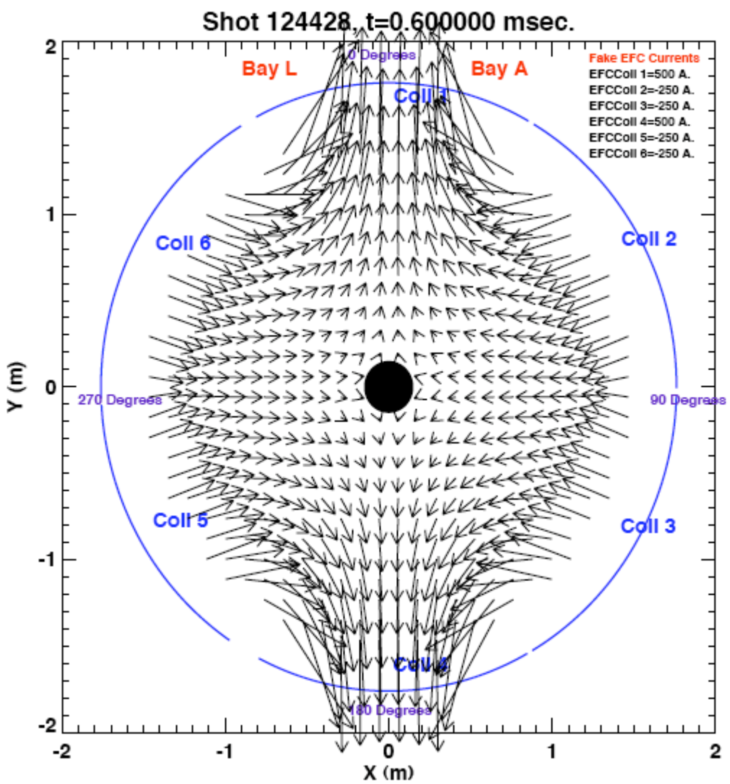
Edge rotation collapse occurs *before* SPA Current in all shots.

# Where does this data lead…

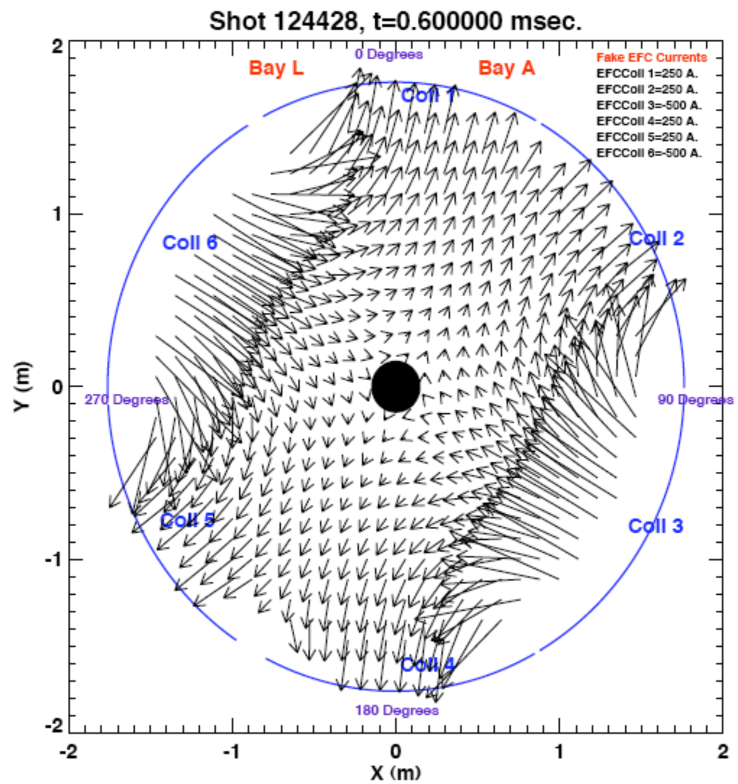
- Comparison of applied field to EF source from PF5 non-circularity or other known EF sources.
  - Near term analysis task.
- Optimize n=3 correction in parallel with RWM/DEFC feedback.
  - Proposed by JEM in the ASC group.
- Optimize EFC using only single coils near PF leads.
  - My be propsed by D. Gates (based on group review).
- Experiments to asses the presence of n=2 error fields.
  - The present XP proposal.

# Sign Conventions On Coils

0° Configuration

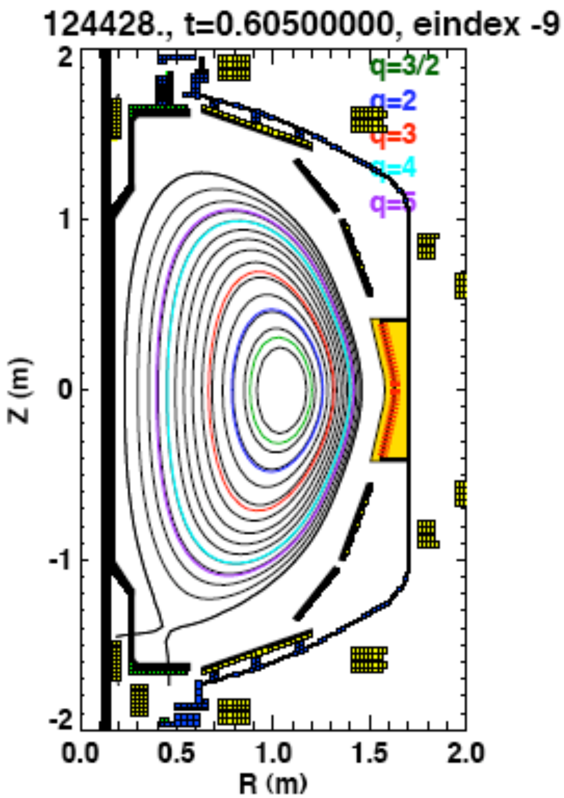



30° Configuration




- “Engineering” Toroidal Angle Increasing CW As Viewed From Top.
- Positive RWM Current Pointing OUT of the vessel (“Physics” Convention).

# Shot Plan: Target (I)




A) Preparation:

i) Take SPA compensation shots for the even EFC Coil Configuration: **(3 shots)**

| Shot To Reload | Shot Taken |
|---|---|
| 126917 | |
| 126918 | |
| 126920 | |

ii) Reproduce target plasma: Shot 124411 **(2-5 shots)**

800kA, 4.5kG LSN NBI heating discharge, H-mode at 113 msec.

Shot should suffer rotation collapse and RWM at ~.9 sec.

Note: the inner gap is sensitive to the CS gas plenum pressure for this shot. Need to watch this variable carefully. Optimum for last year was 900 T.

Reference : 124411

$I_p = 800kA$

$\kappa \approx 2.2$

$\delta$ upper/lower = .35/.65

$B_T = 4.5kG$

$q_{95} \approx 9$

Inner/Outer Gap = 5cm/12cm

Deuterium Gas

NBI Voltages = 90/90/80

No LITER

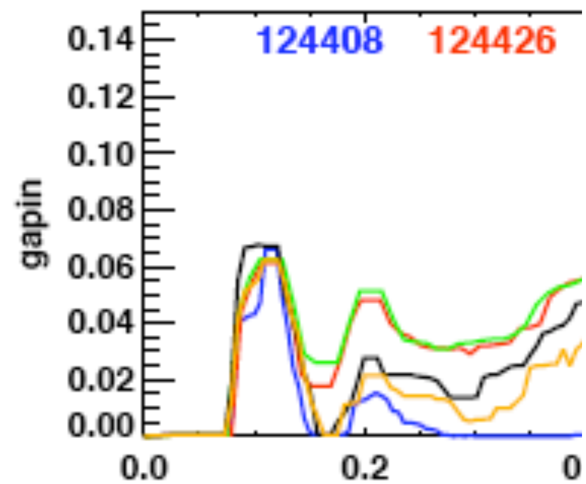
No RF

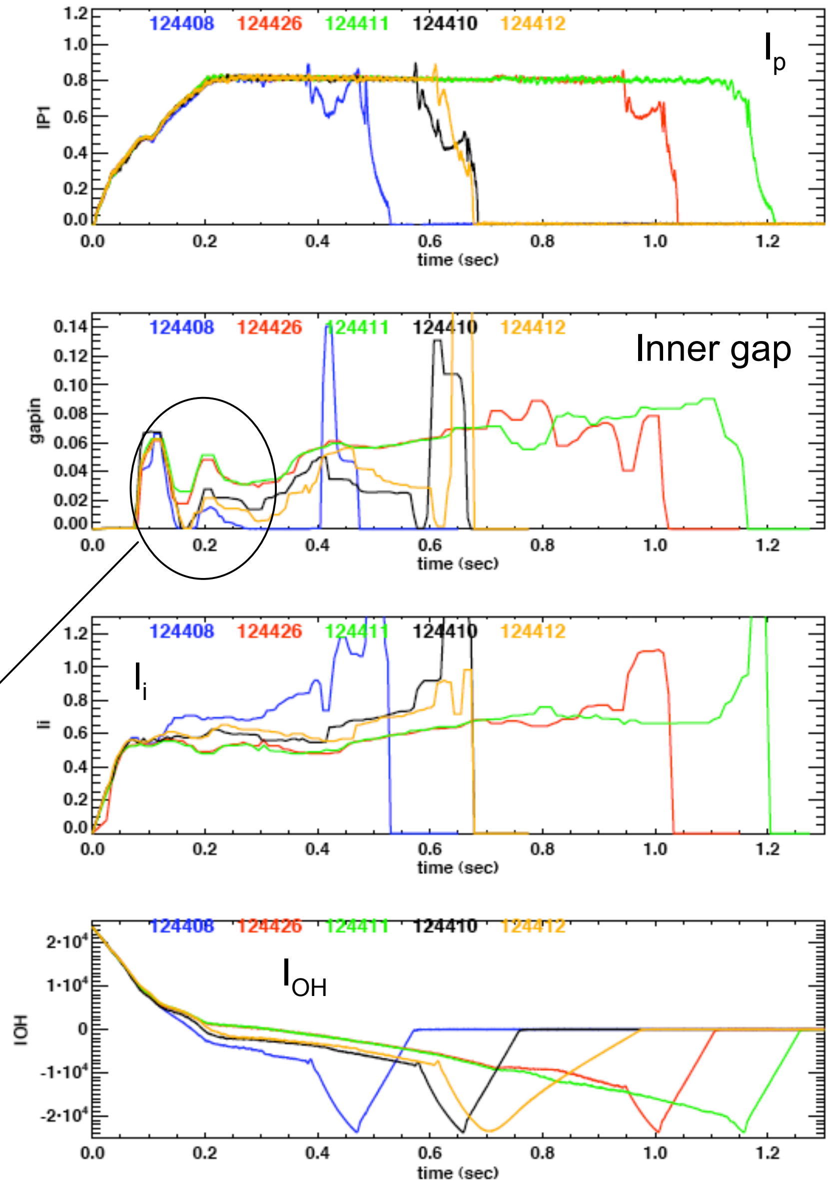
No CHI

# Shot Plan: Target (II)

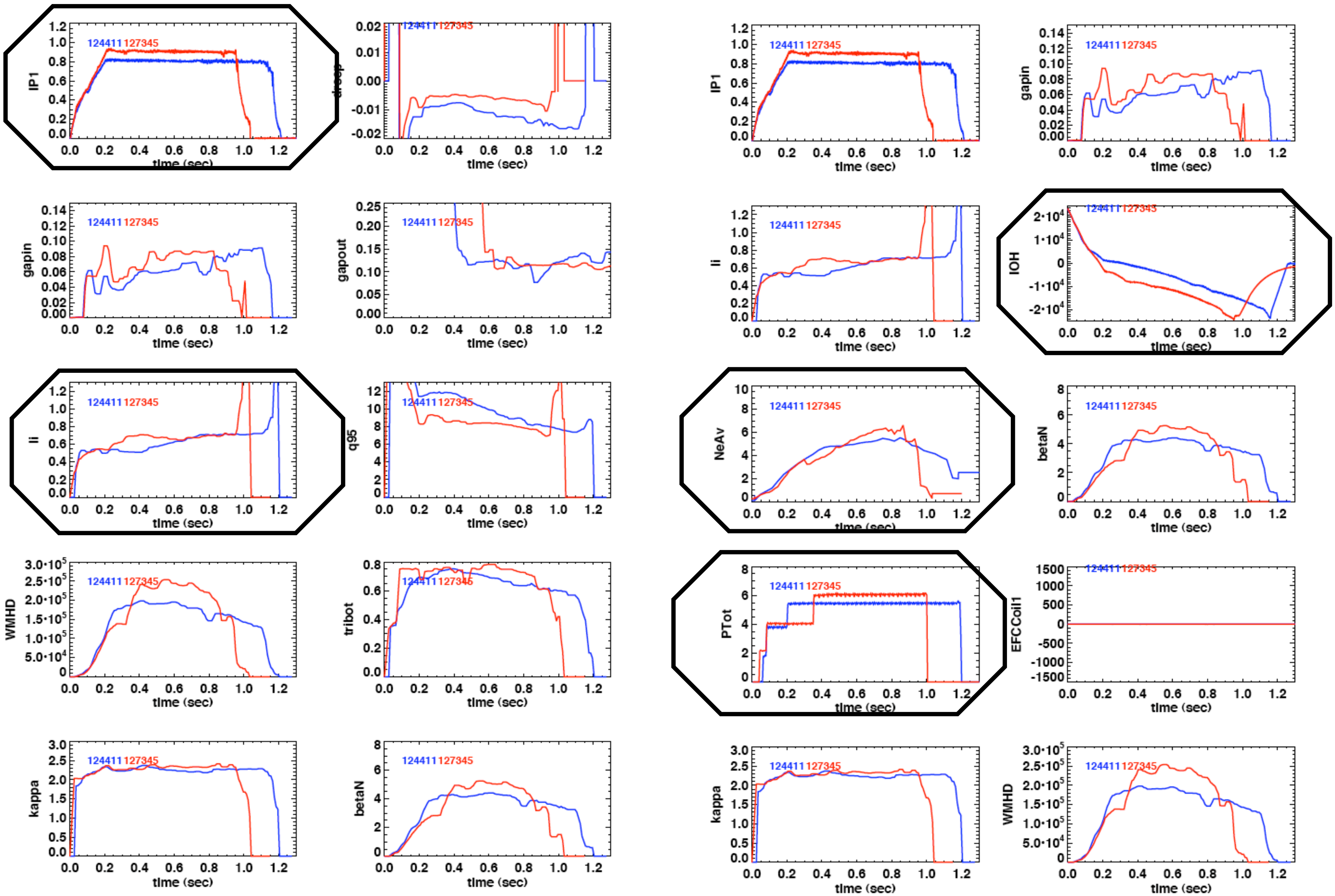
- Target development during 701 focused on CS plenum pressure.
- Discharges with higher pressures brushed CS, settled on 900 T.

122408: 1200 T
122410,122412: 1000 T
124411: 900 T
124426: 850 T



# Shot Plan: Target (III) Target Compared to Monday's Fiducial



# Shot Plan (II): Look for Asymmetric Response

**B**) Scan of n=2 applied field phase/magnitude **(12 shots)**

Six phases with two magnitudes each. SPA Currents turning on at .35, ramping to full value by 0.4 seconds, on for remainder of shot (100 msec earlier than in 701, timing may be modified).

Note that these are the currents leaving the SPA Units, which are connected so that positive SPA current makes field into NSTX, i.e. negative EFC field for the physics convention.

i)

| Phase | SPA 2 (A) | SPA 3 (A) | SPA 1 (A) | Shot |
|---|---|---|---|---|
| 90 | 250 | -125 | -125 | |
| 90 | 500 | -250 | -250 | |
| 0 | -250 | 125 | 125 | |
| 0 | -500 | 250 | 250 | |

ii)

| Phase | SPA 2 (A) | SPA 3 (A) | SPA 1 (A) | Shot |
|---|---|---|---|---|
| 150 | -125 | 250 | -125 | |
| 150 | -250 | 500 | -250 | |
| 60 | 125 | -250 | 125 | |
| 60 | 250 | -500 | 250 | |

iii)

| Phase | SPA 2 (A) | SPA 3 (A) | SPA 1 (A) | Shot |
|---|---|---|---|---|
| 30 | -125 | -125 | 250 | |
| 30 | -250 | -250 | 500 | |
| 120 | 125 | 125 | -250 | |
| 120 | 250 | 250 | -500 | |

# Shot Plan (III): EFC optimization and RWM critical rotation with n=2 braking.

**C**) Optimization of n=2 EF correction for long pulse discharges **(up to 5 shots)**

i) Determine phase of optimal n=2 correction data collected in step B). Optimal direction will have best sustained rotation, longest pulse length. If no asymmetry was observed in step B, then skip to part D.

ii) Increase/Decrease EFC coil current in 250 A increments in order to optimize the discharge (i.e. maximum rotation and pulse length)

| Optimal Phase | SPA 2 (A) | SPA 3 (A) | SPA 1 (A) | Shot |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**D**) RWM Critical Rotation Profile with n=2 braking **(5 shots)**

*i) If step C was executed (n=2 EF was identified), then:* the baseline for this step is the optimal discharge from step C.
*If step C was not executed (no n=2 EF), then:* of the configurations from B can be utilized as the baseline.

Record shot number for baseline discharge in this step:__________

ii) Further increase the EFC coil current in the optimal direction, so that EF braking is over compensated and a collapse occurs. Repeat this step with 200A increments of the EFC coil current.

| Optimal Phase | SPA 2 (A) | SPA 3 (A) | SPA 3 (A) | Shot |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

# Shot Plan (IV): Critical Rotation and Damping with an n=6 Perturbation.

**E)** Addition of n=6 braking to optimized n=2 correction **(up to 7 shots)**

*i) If step C was executed (n=2 EF was identified),* then utilize the optimum discharge from Step C as the baseline discharge for this step.
*If step C was not executed (no n=2 EF),* then utilize reference discharge as the baseline discharge for this step.

Record shot number for baseline discharge in this step:___________

ii) Add an n=6 perturbation to the baseline discharge in 500A increments until rotation collapse and RWM is induced. SPA waveform to be same as in step B. Once damping is strong enough, cease to add additional field and move to part iii).

| SPA Current added to Reference Shot (all three SPA units) (A) | Shot |
|---|---|
| 500 | |
| 1000 | |
| 1500 | |
| 2000 | |
| 2500 | |

iii) Repeat the shot in part ii) with sufficient n=6 damping and n=2 correction.

iv) If n=2 correction was applied, repeat shot in iii) without n=2 correction.

# EFC Coil Connections Are Important!

## 4. Required machine, NBI, RF, CHI and diagnostic capabilities

The usual diagnostic capabilities are required, NBI voltage on A,B,C = 90,90,80kV

No RF or CHI.

Most critical diagnostics are for this XP: CHERS, MPTS, MSE, Equilibrium Magnetics, Fast Mirnovs, RWM/LM sensors, USXR

RWM coils will need to be in the "Even Connection" or "Series Connection" configuration. The mapping of the SPAs to coils will thus be:

| Supply | Coils (Physics Sign Convention) |
|---|---|
| SPA 1 | -3, -6 |
| SPA 2 | -1, -4 |
| SPA 3 | -2, -5 |

Note: The (physics) sign convention above is based up current being sourced into the physical "positive" lead of the RWM coils, such that positive current makes magnetic field pointing into the vessel, i.e. negative field.

***In order to switch from the traditional anti-series connection, the following step must be taken inside the interface box in the NTC.***

1: Remove all three plates labeled BB

2: Remove the following jumpers:

SU1P to 6A

SU2P to 4A

SU3P to 5A

3: To put coils 3 & 6 in the even configuration:

Add jumper between 3B and 6A

Add jumper between 6B and SU1P:

4: To put coils 2 & 5 in the even configuration:

Add jumper between 2B and 5A

Add jumper between 5B and SU3P:

5: To put coils 1 & 4 in the even configuration:

Add jumper between 1B and 4A

Add jumper between 4B and SU2P

***A test shot should be taken to confirm this connection***. A suggested set of waveforms for this test-shot is:

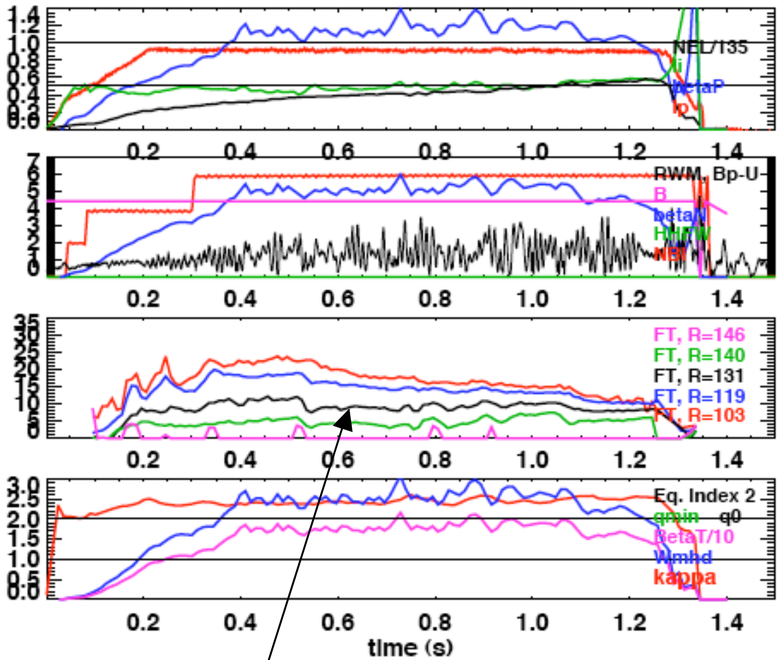
SPA 1: +500A from 0 to .1, -500A from .1 to .2

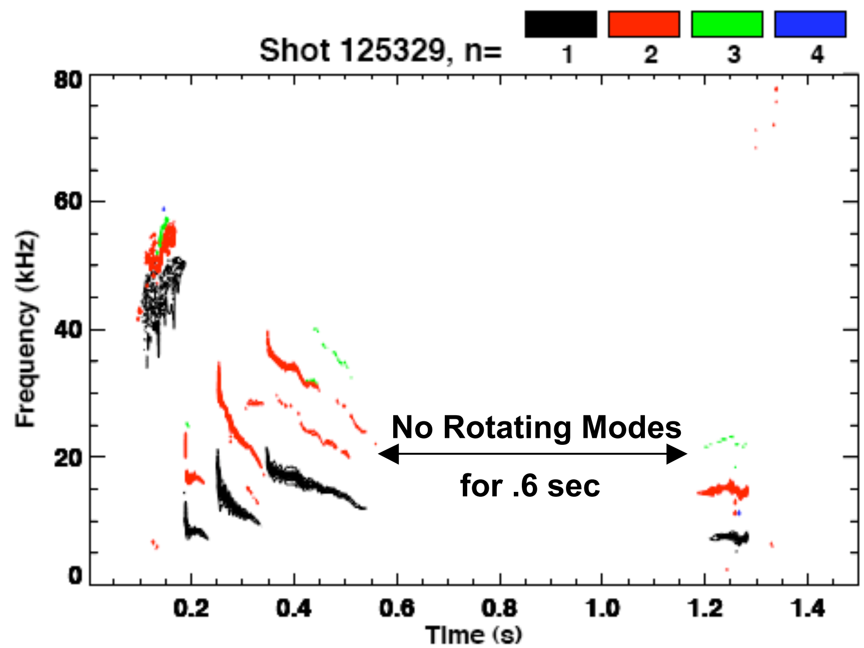
SPA 2: +700A from .4 to .5, -700A from .5 to .6

SPA 3: +900A from .8 to .9, -900A from .9 to 1.0

# Other Stuff

# n=3 preprogrammed correction + n=1 DEFC resulted in longest ever 900kA discharge




- Excellent sustainment of toroidal rotation.

# Look at Spectrum of Applied Field

- Calculate the magnetic spectrum in Hamada coordinates *(straight field lines + Jacobian Constant on Flux Surface)*

$$B = \sum_{m,n} B_{nms} \sin(m\vartheta - n\varphi) + B_{nmc} \cos(m\vartheta - n\varphi)$$

$\vartheta$ : Hamada poloidal angle

$\varphi$ : Hamada toroidal angle

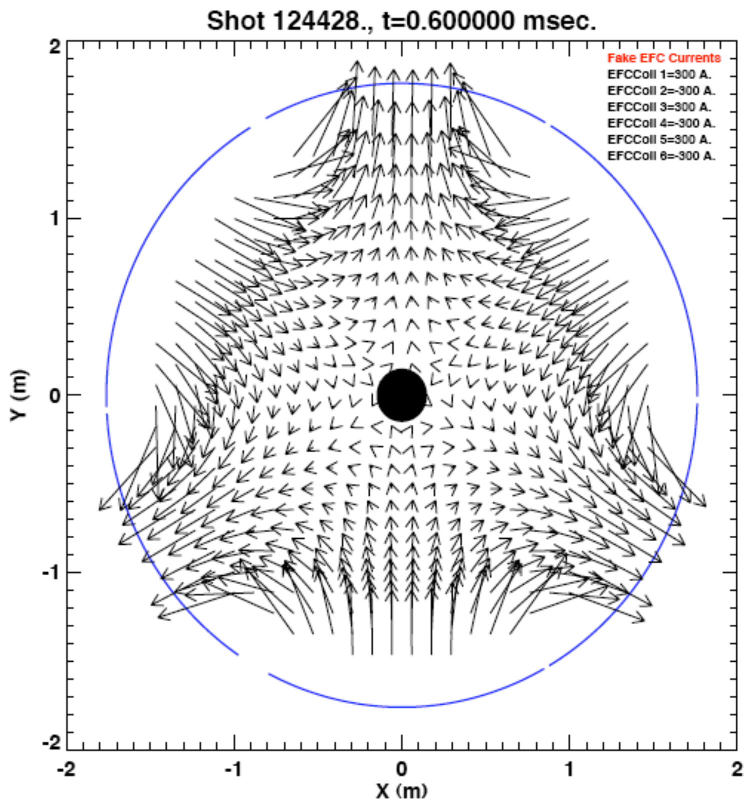
- Look for unexpected features in the spectrum.
- Compute a term indicating NTV strength.

$$\text{NTV Factor} = n^2 \sum_{m} \left(B_{nms}^2 + B_{nmc}^2\right)$$

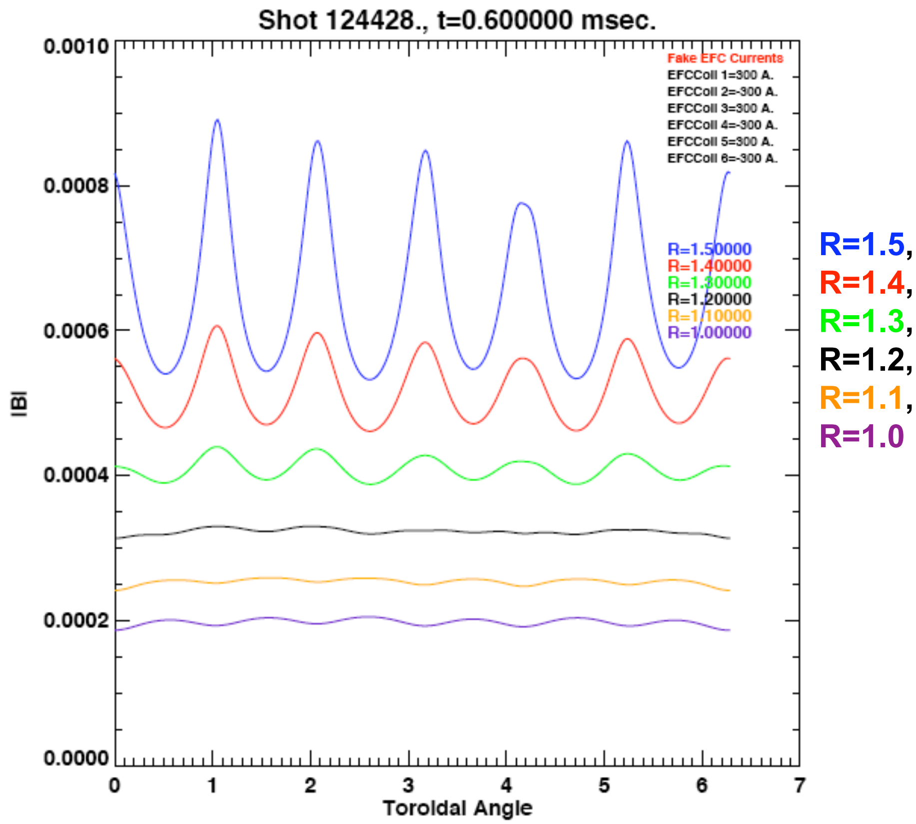
- Use codes developed by JEM and JKP

# Fairly Pure n=3 Spectrum Applied in XP701 (I)

View From Top of NSTX



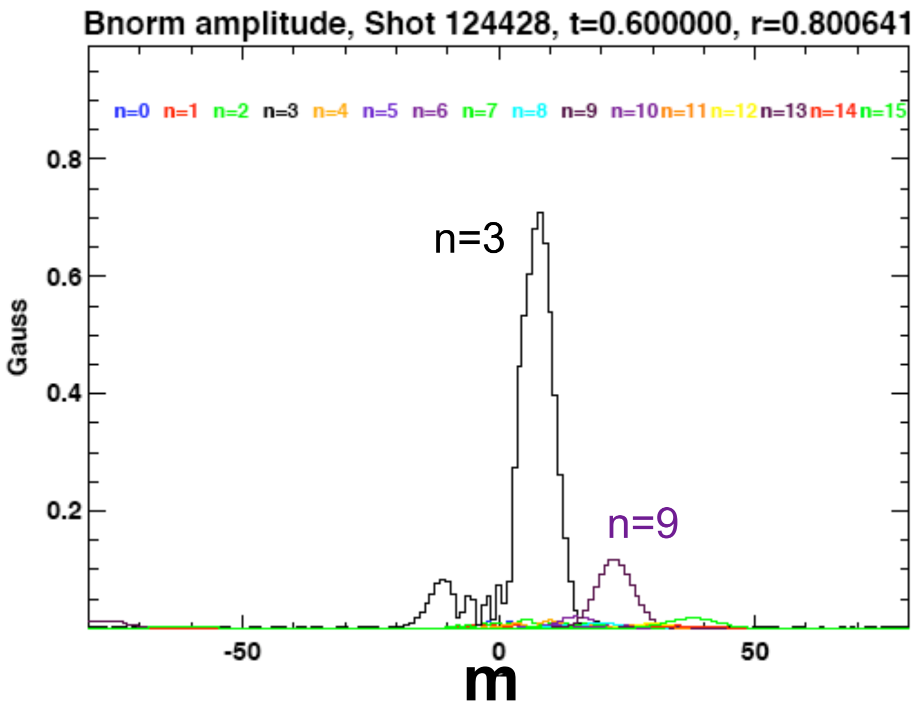

|B| along circle at fixed radius



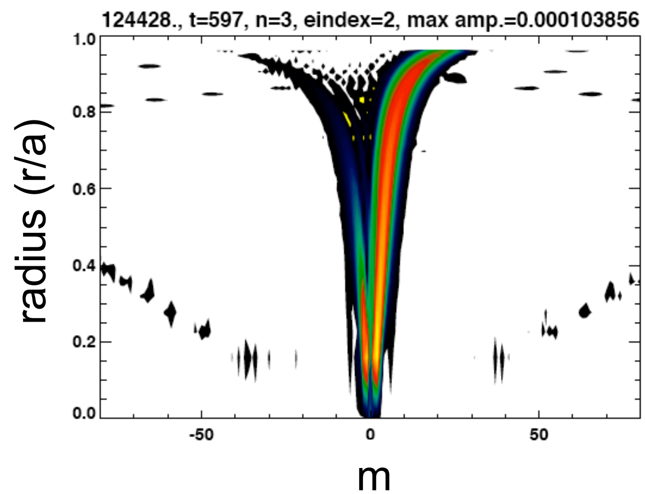

*Call this the "n=3 configuration"*

# Fairly Pure n=3 Spectrum Applied in XP701 (II)

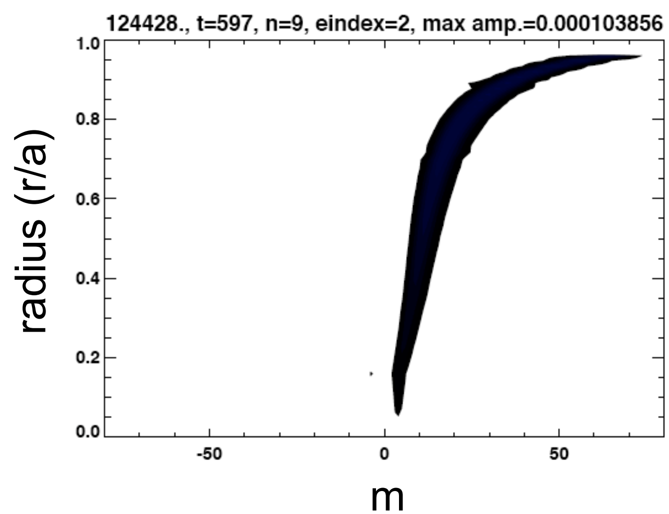
Spectrum at r/a=0.8




Radial dependence of n=3 components

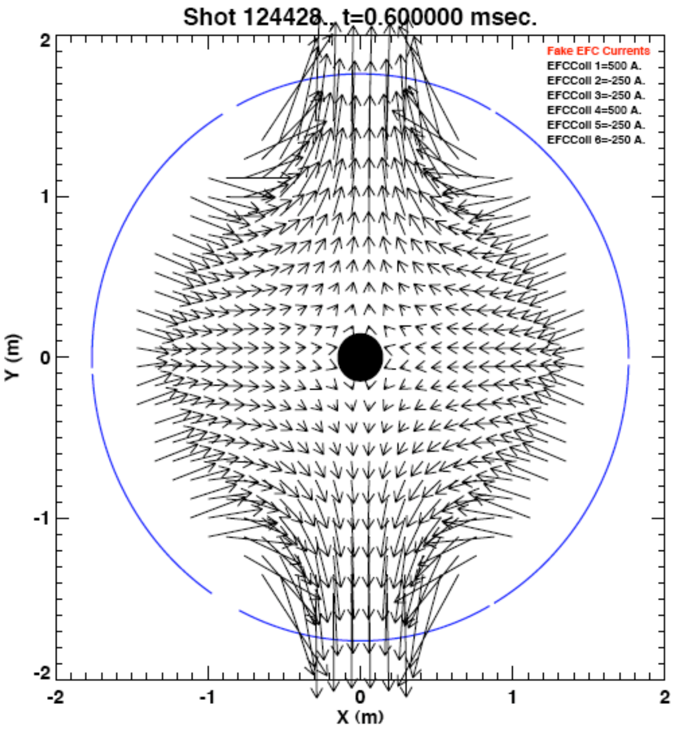



Radial dependence of n=9 components

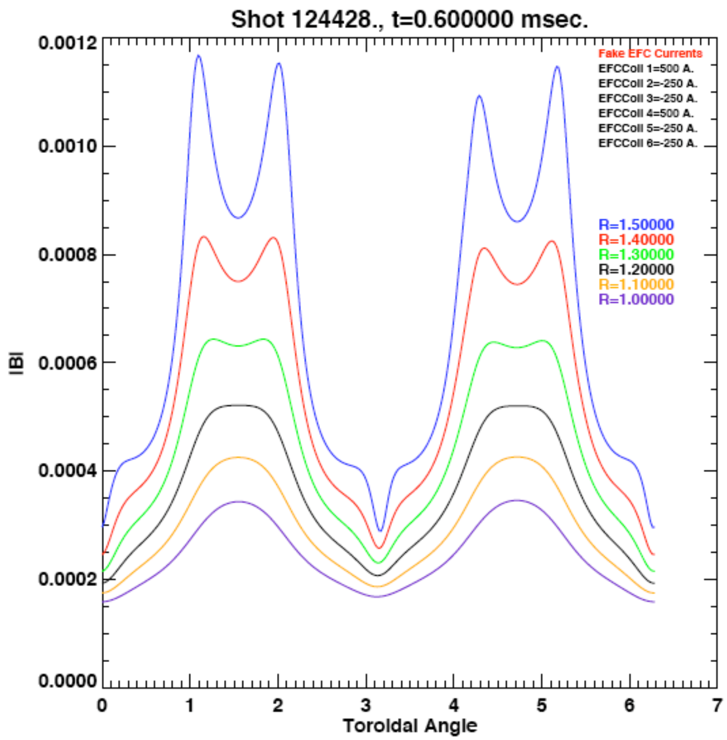


# Large n=2 & 4 perturbations with “n=2” EFC coil connections (I)

View From Top of NSTX




|B| along circle at fixed radius

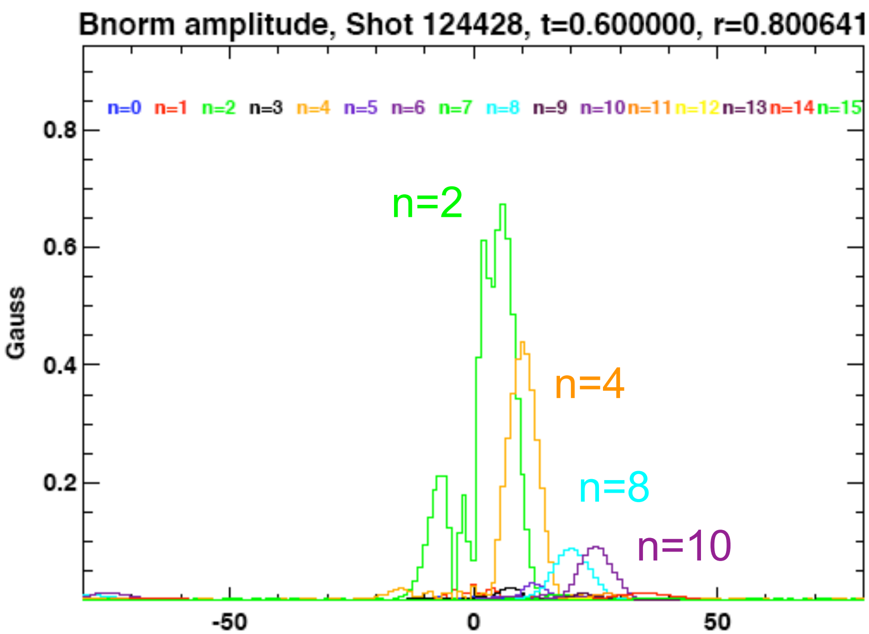



R=1.5,
R=1.4,
R=1.3,
R=1.2,
R=1.1,
R=1.0

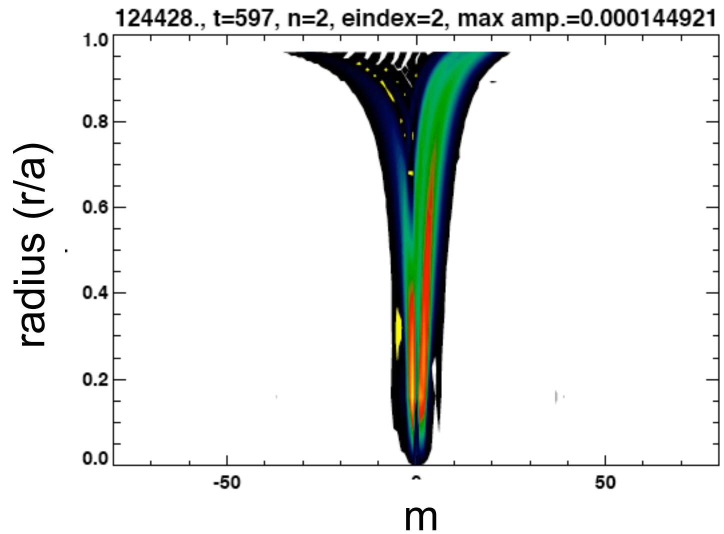
*Call this the “n=2 configuration”*

# Large n=2 & 4 perturbations with “n=2” EFC coil connections (II)

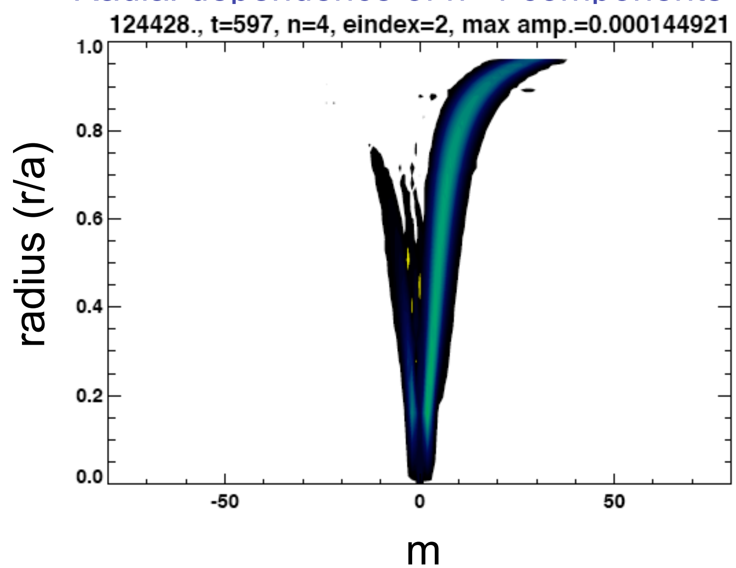
Spectrum at r/a=0.8



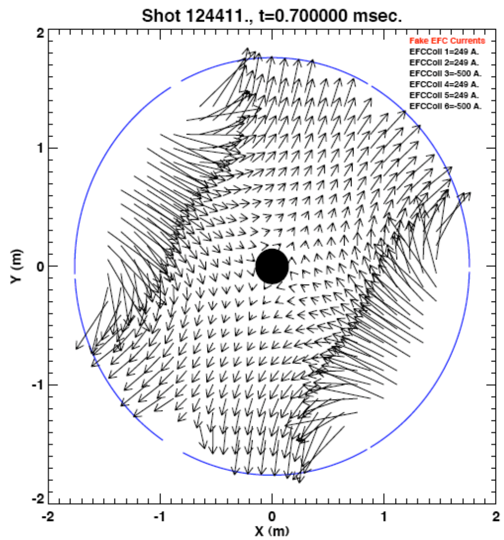

Radial dependence of n=2 components

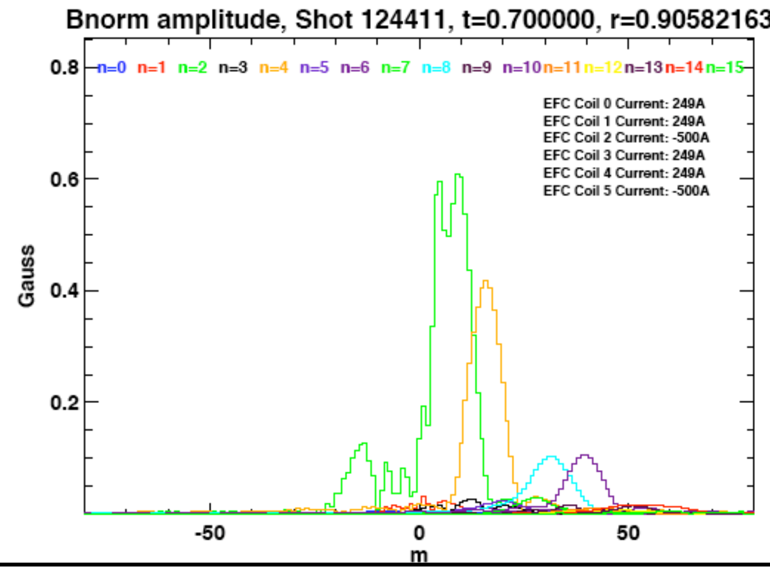



Radial dependence of n=4 components

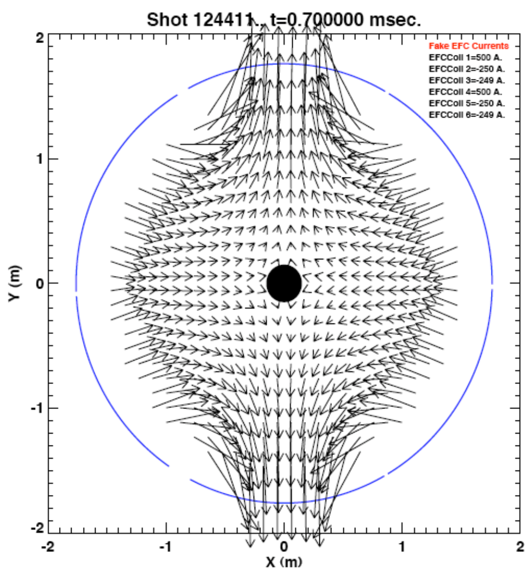


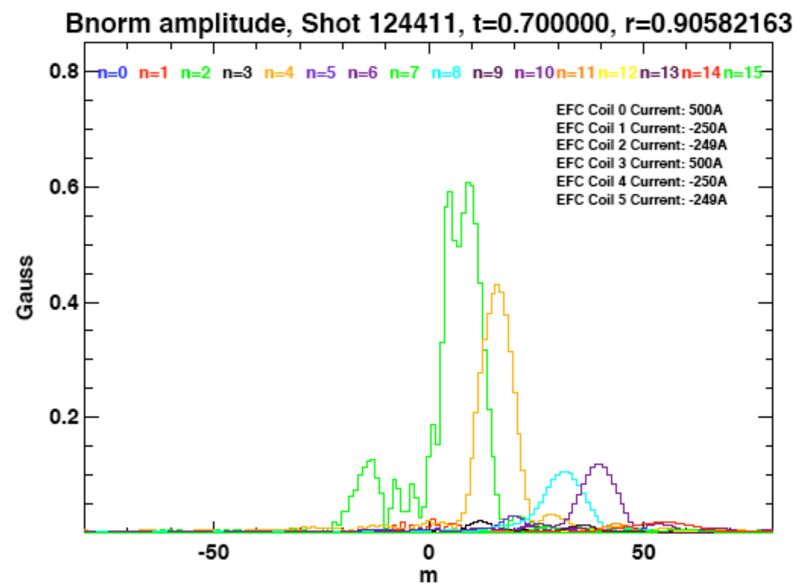
# The Optical Illusion




<u>"30-Degrees"</u>
Coil 1: 250 A
Coil 2: 250 A
Coil 3: -500 A
Coil 4: 250 A
Coil 5: 250 A
Coil 6: -500 A



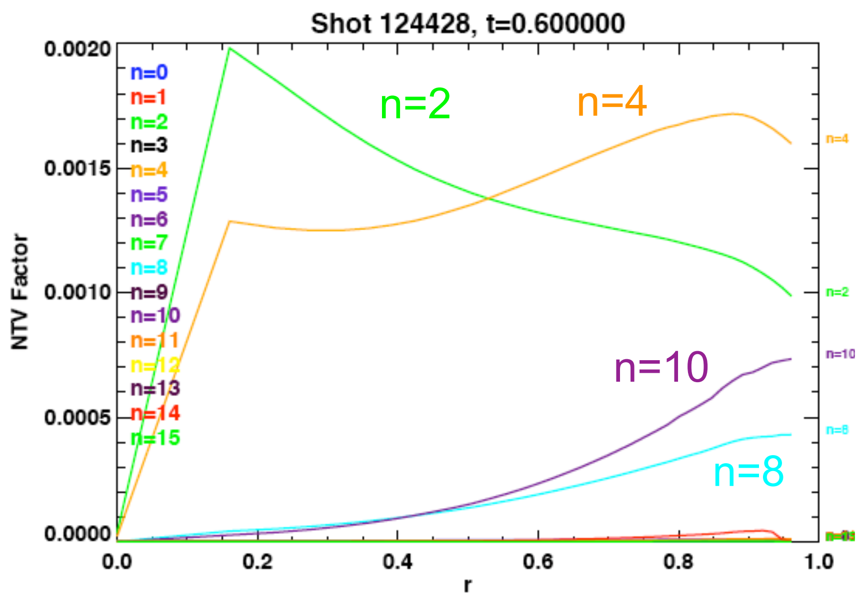




<u>"0-Degrees"</u>
Coil 1: 500 A
Coil 2: -250 A
Coil 3: -250 A
Coil 4: 500 A
Coil 5: -250 A
Coil 6: -250 A

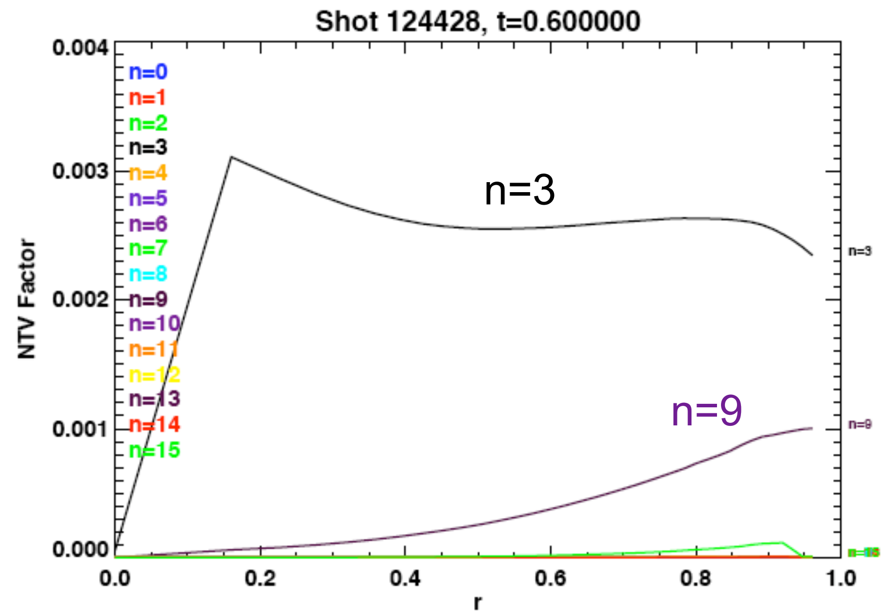
# Strong NTV Contributions from "unintended" terms

$$\text{NTV Factor} = n^2 \sum_m \left( B_{nms}^2 + B_{nmc}^2 \right)$$

n=2 Configuration




n=3 Configuration

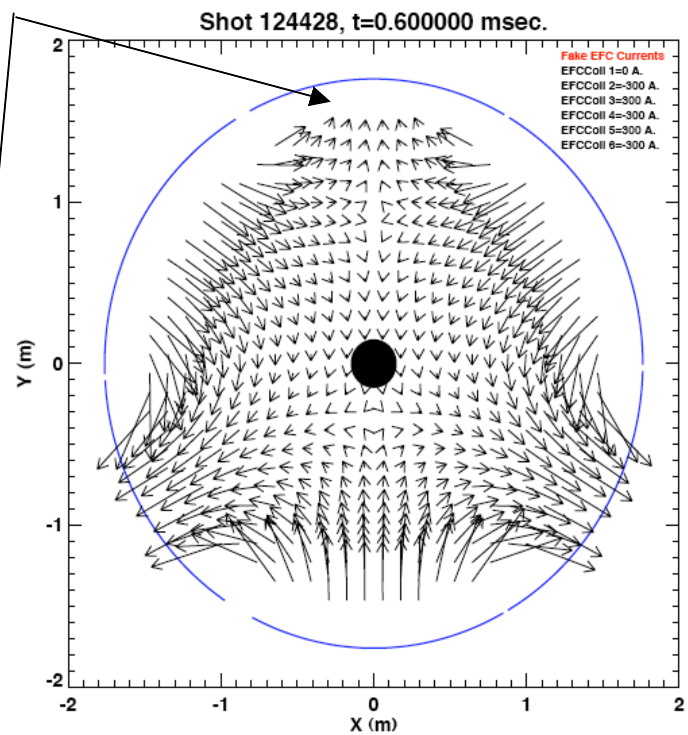



*Q1: If rotation is maintained better with correction, is it an n=2 or n=4 EF that is being corrected?*

*Q2: How important is the plasma response for estimating NTV for n>1 perturbations?*

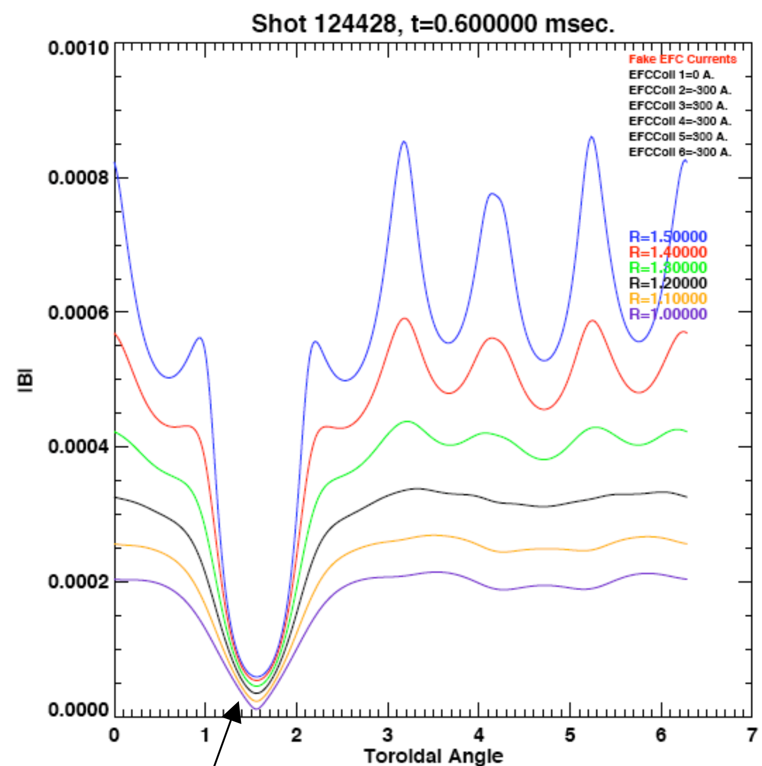
# Additional Cases 2: n=3, missing coil (I)

View From Top of NSTX




Source of huge n=1 perturbation

|B| along circle at fixed radius

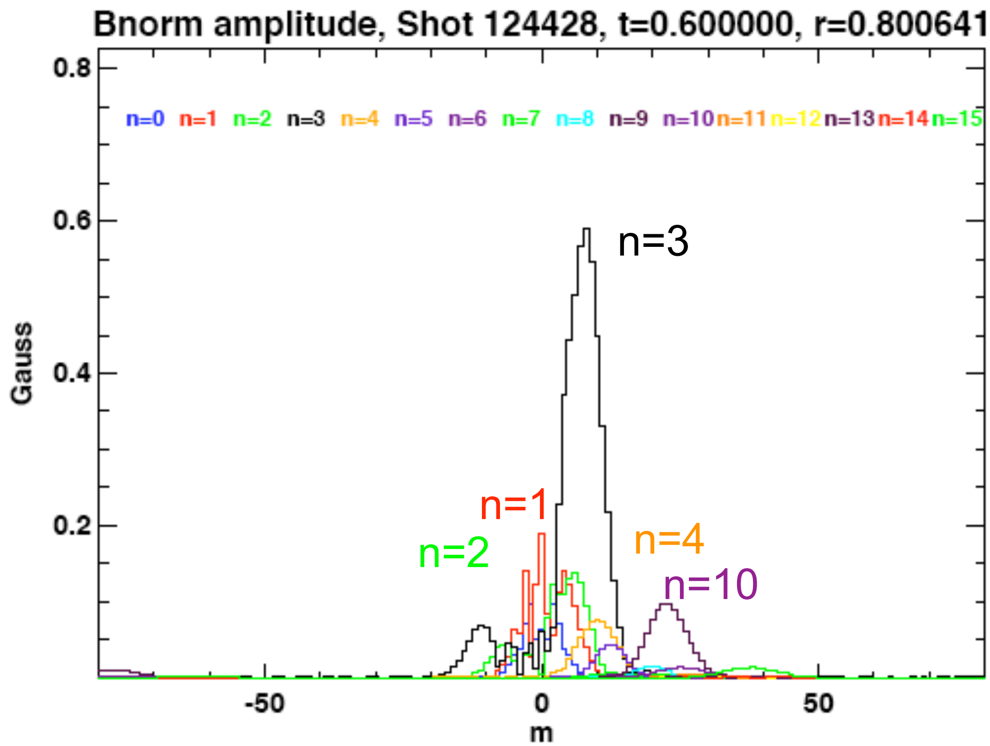



R=1.5, R=1.4, R=1.3, R=1.2, R=1.1, R=1.0

Source of huge n=1 perturbation

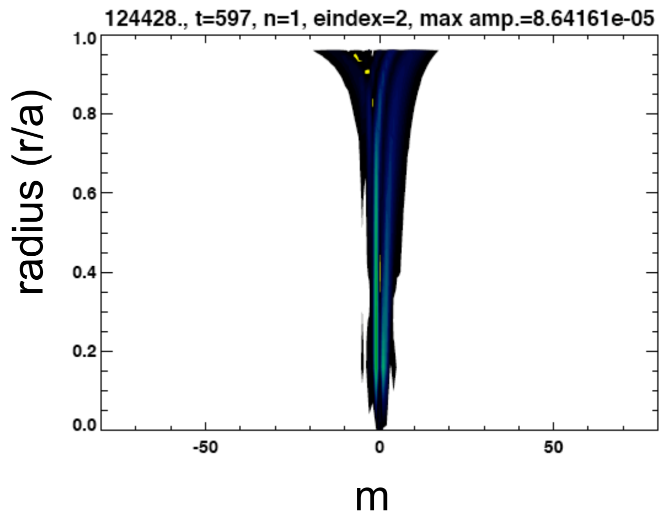
# Additional Cases 2: n=3, missing coil (II)

Spectrum at r/a=0.8

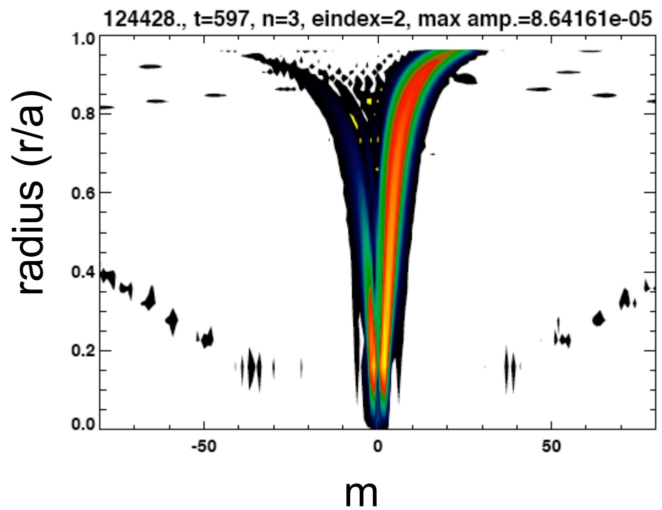



***Many components, including large n=1***

Radial dependence of n=0 components

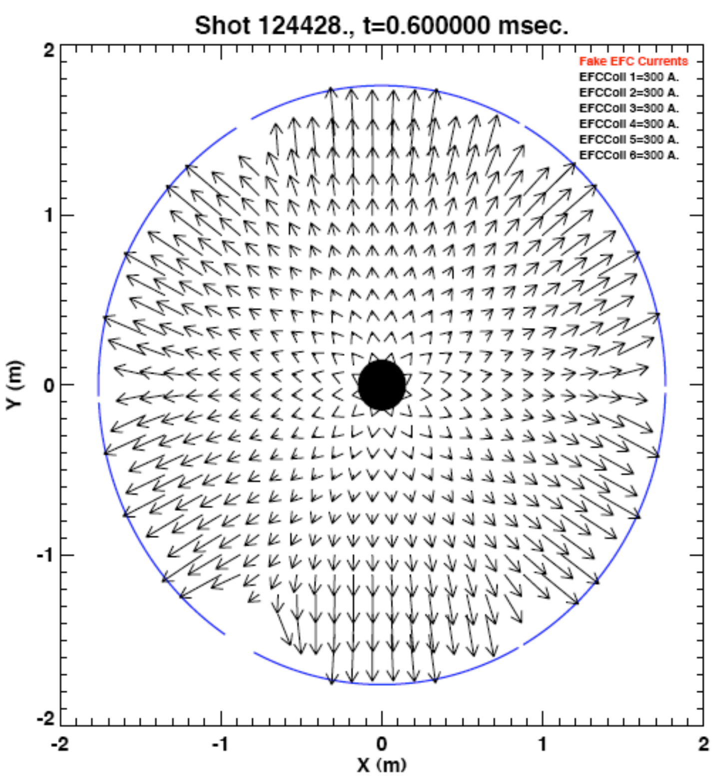



Radial dependence of n=3 components

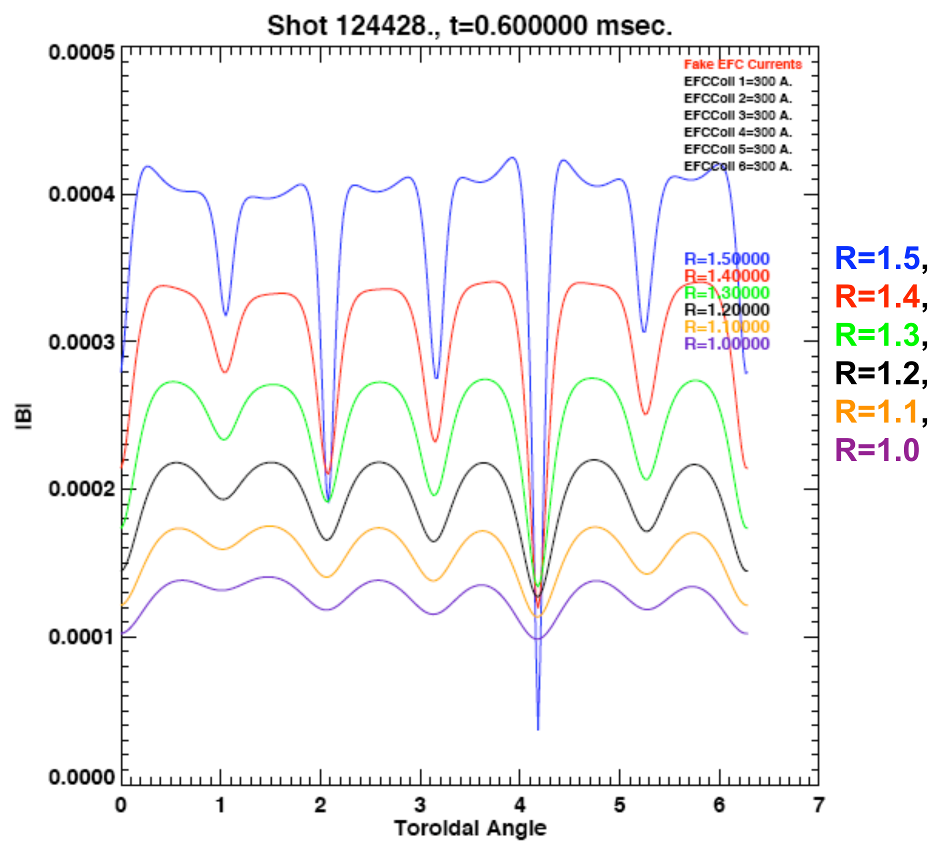


# n=6 perturbation is due to vertical legs of EFC coils. (I)

View From Top of NSTX

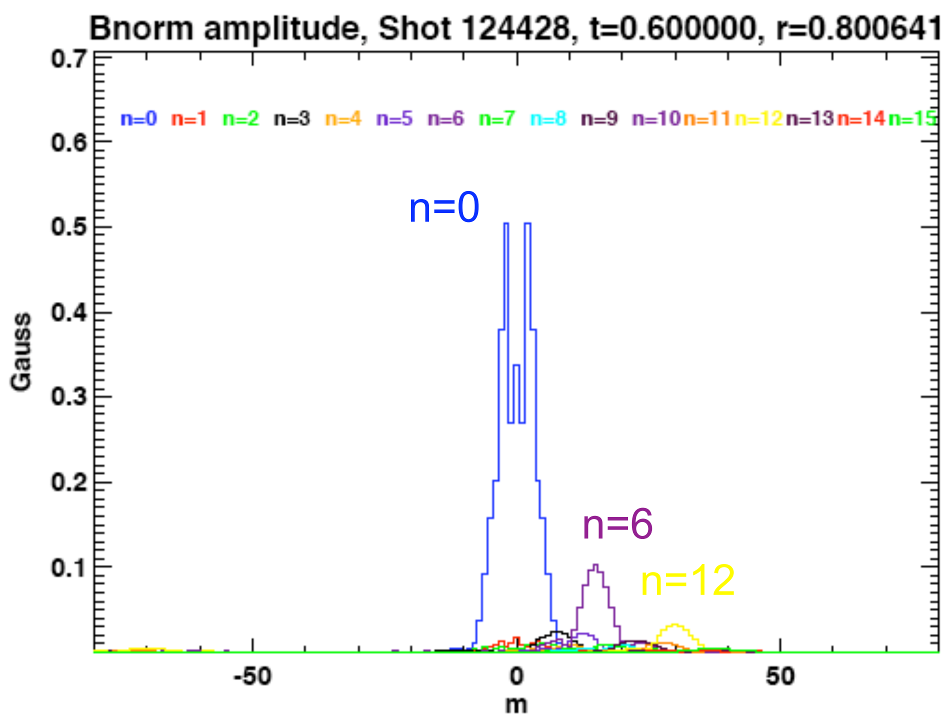



|B| along circle at fixed radius

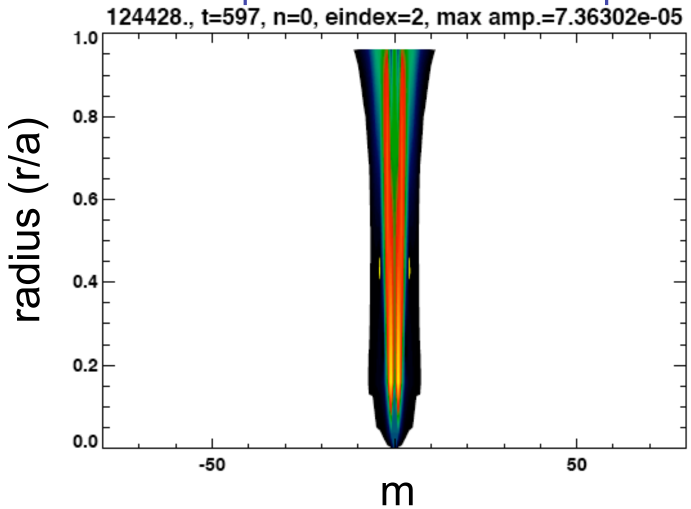


# n=6 perturbation is due to vertical legs of EFC coils. (I)

Spectrum at r/a=0.8




Radial dependence of n=0 components




Radial dependence of n=6 components