Supported by Office of Fusion Energy Sciences — Excellent Science Attractive Energy; Office of Science

NSTX

Results from MHD XP's 701, 702, 703

Presented by:

J.E. Menard, PPPL

w/ contributions from

S. Gerhardt and S. Sabbagh

NSTX Results Review

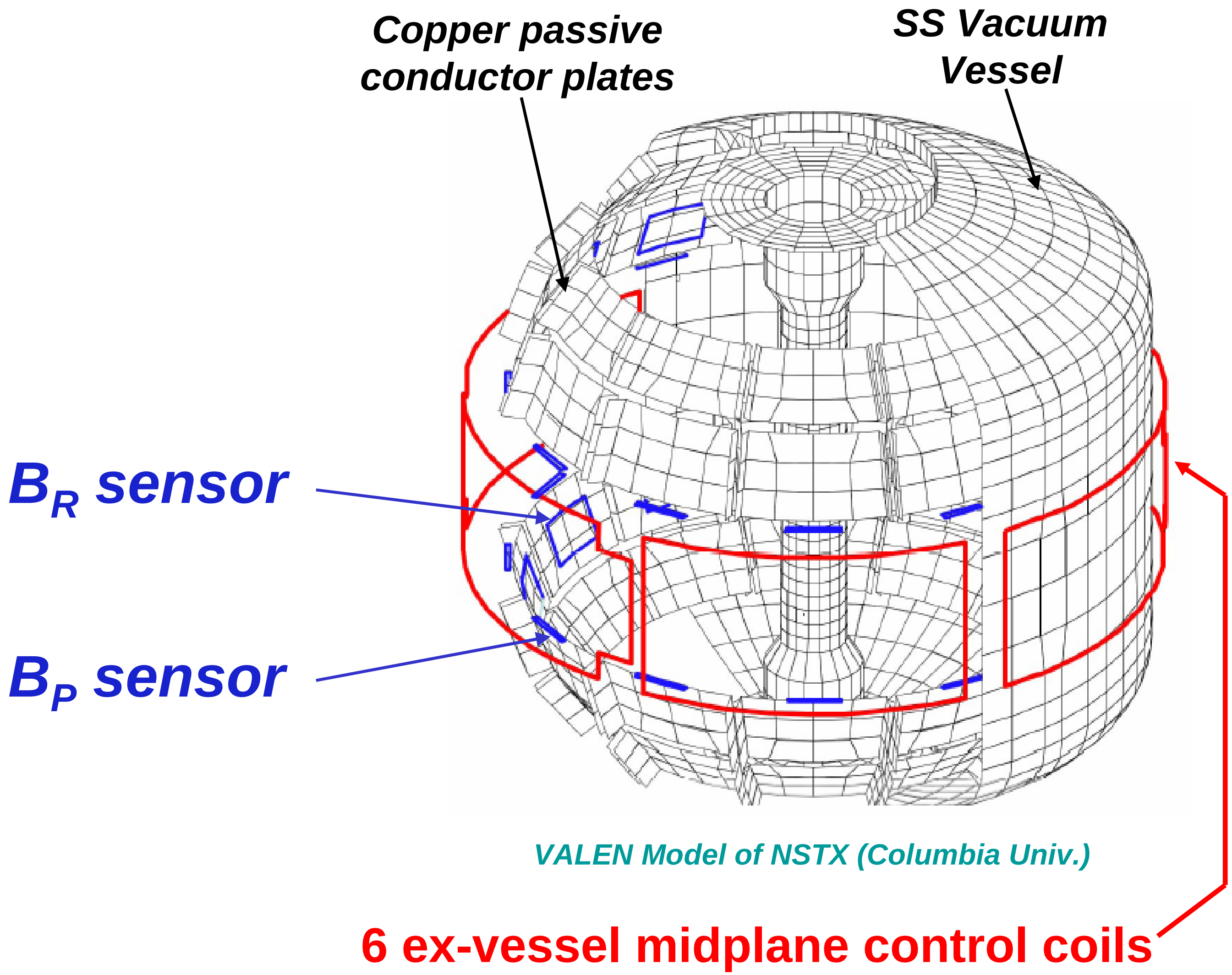
July 23-24, 2007

Princeton Plasma Physics Laboratory

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAERI
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

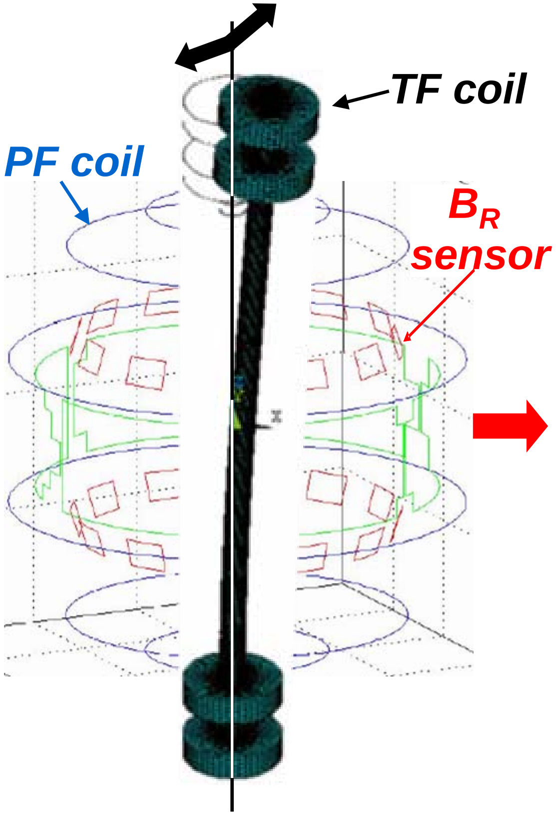
The NSTX RWM/EF coil and sensor system



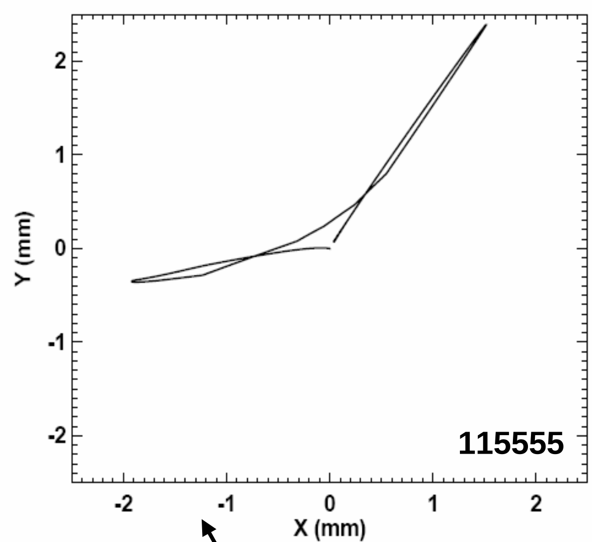
VALEN Model of NSTX (Columbia Univ.)

Error field source identification and compensation in NSTX

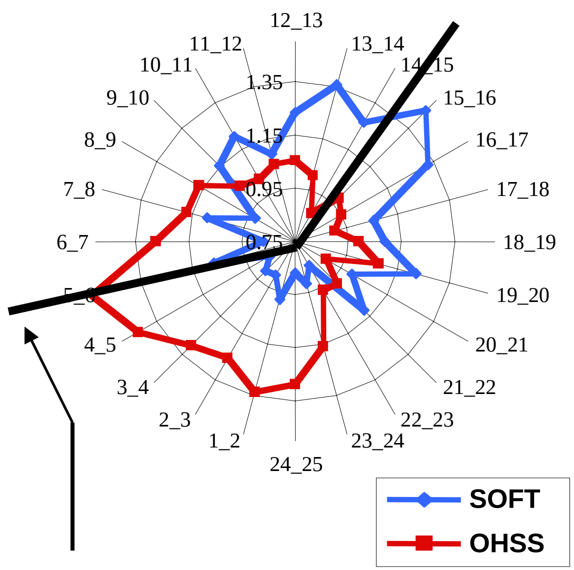
- Some scenarios with lower κ, δ exhibit Ω_ϕ and β_N collapse when β_N > β_N (no-wall)
- Measure 2-3 Gauss $B_\perp^{2/1}$ EF in LM experiments… what is EF source?
- **Present picture of EF Source:** EF from/near OH leads at top of machine induces **TF coil motion relative to** B_R sensors (plates, vessel) and thus **the PF coils**



TF coil shift at mid-plane
inferred from B_R sensors
during OH+TF vacuum shot



Normalized TF bottom joint voltage drop from OH+TF test



TF flag-joint voltage variation direction consistent with magnetics

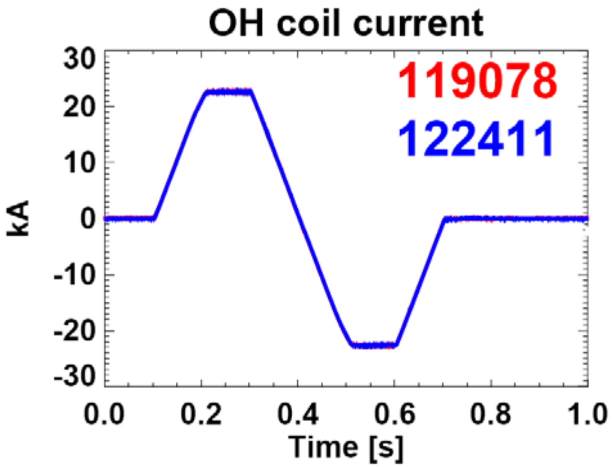
Shim between TF bundle and OH tension tube added before 2007 run to reduce motion

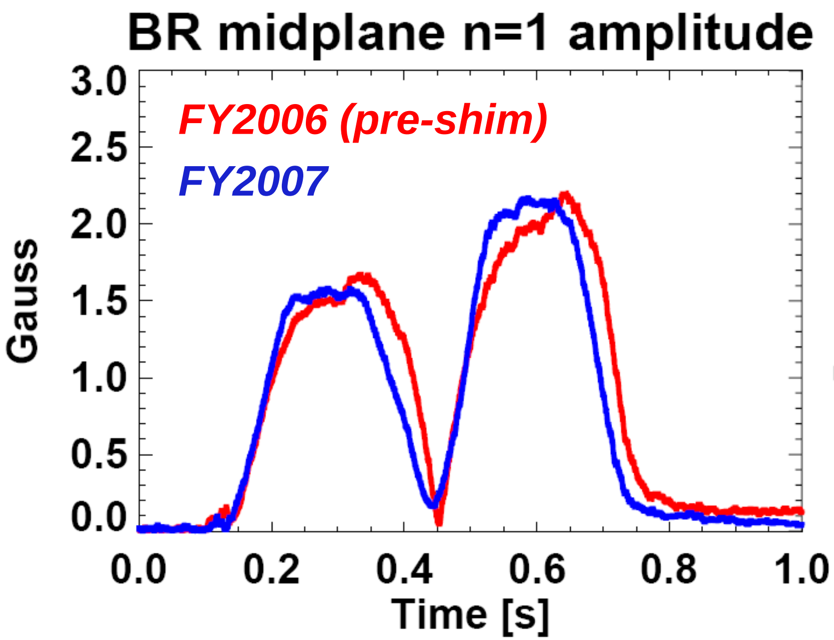
XP701 - Assessment of intrinsic error fields after TF centering

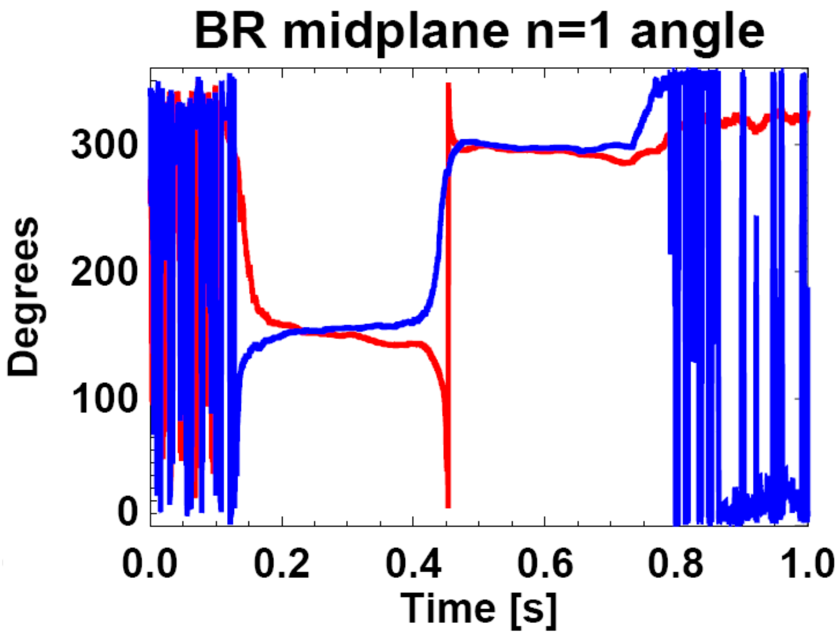
- Assessed modifications to TF coil centering w.r.t. intrinsic EF
  - Intrinsic EF very similar to 2006 for LM ohmic shots
  - Larger difference for long-pulse – lower EF after I_{OH}=0 crossing
- Verified rotation response asymmetry to n=1 applied field
- Could not reproduce 2006 reference discharge for OHxTF EFC algorithm optimization (rotation collapse not observed)
  - Used externally applied n=1 pulses instead in XP702
- NEW: Measured plasma response asymmetry to n=3
  - Pulse-length increases with "corrective" n=3
  - Rotation increases with "corrective" n=3

Error field from fast OH variation largely unchanged

- OH waveform similar to that in ohmic discharges used for locked-mode experiments

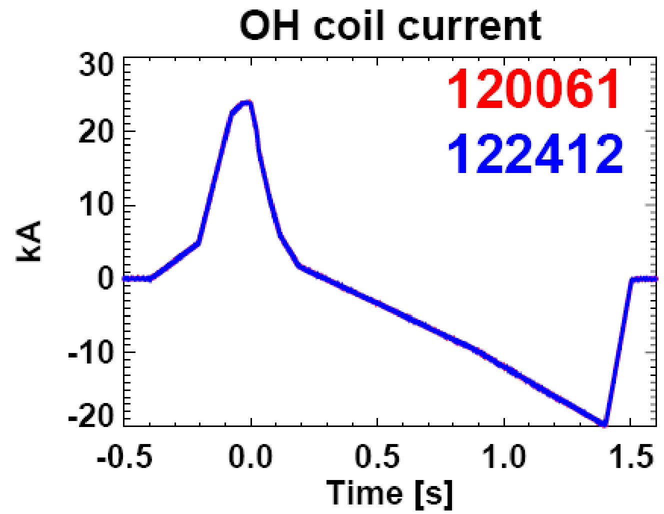


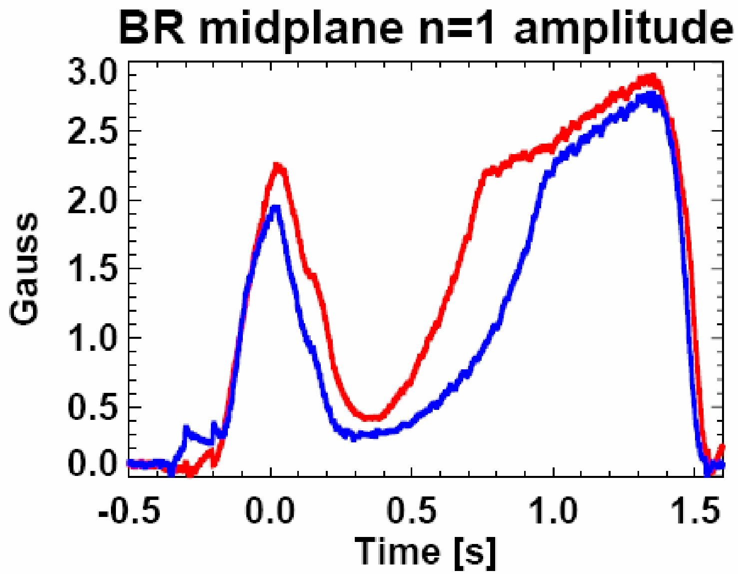


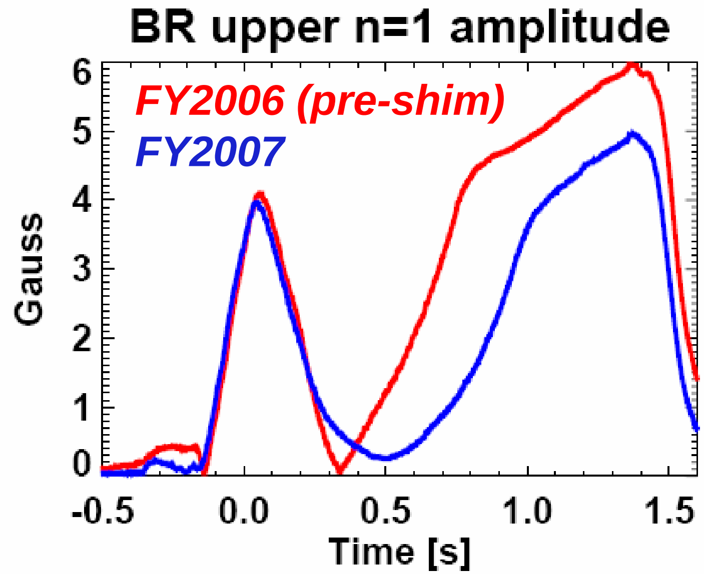


EF from slow OH variation different after I_{OH}=0 crossing

- OH waveform similar to that for NBI H-mode long-pulse
- EF increase is delayed after I_{OH} crossing, but eventually reaches similar amplitude and slope
- Midplane EF amplitude similar, upper EF amplitude reduced late in shot

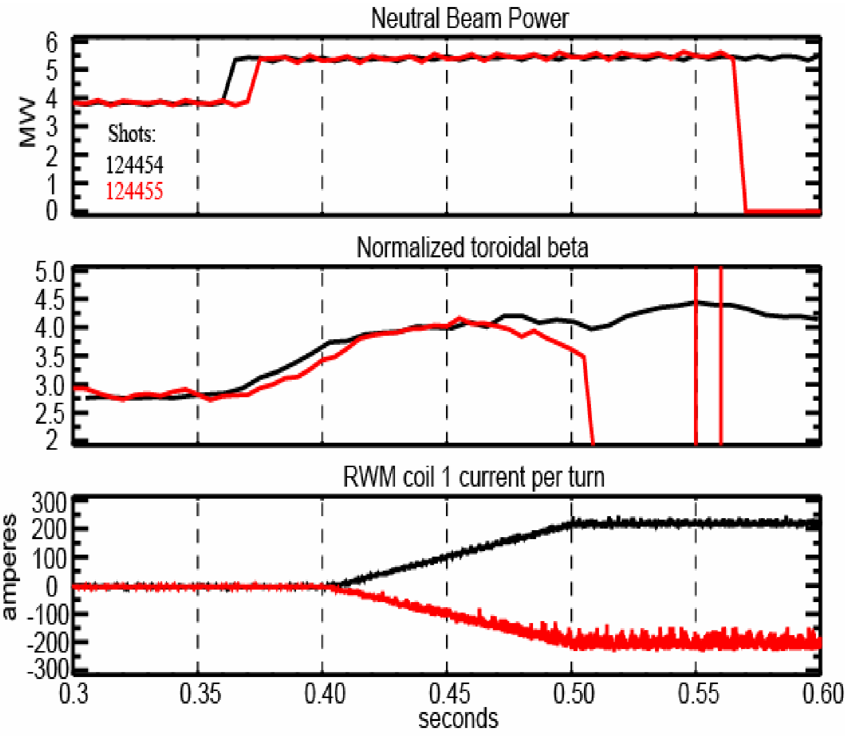


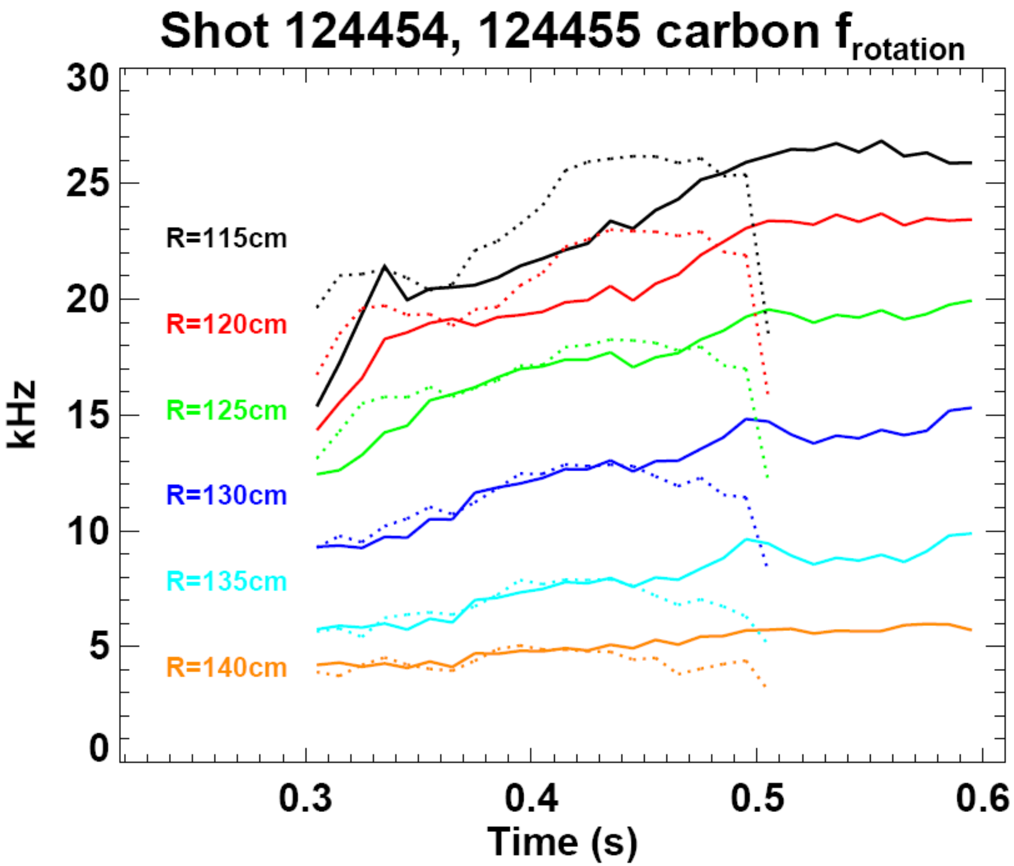




Plasma still exhibits asymmetric response to phase of applied n=1 field

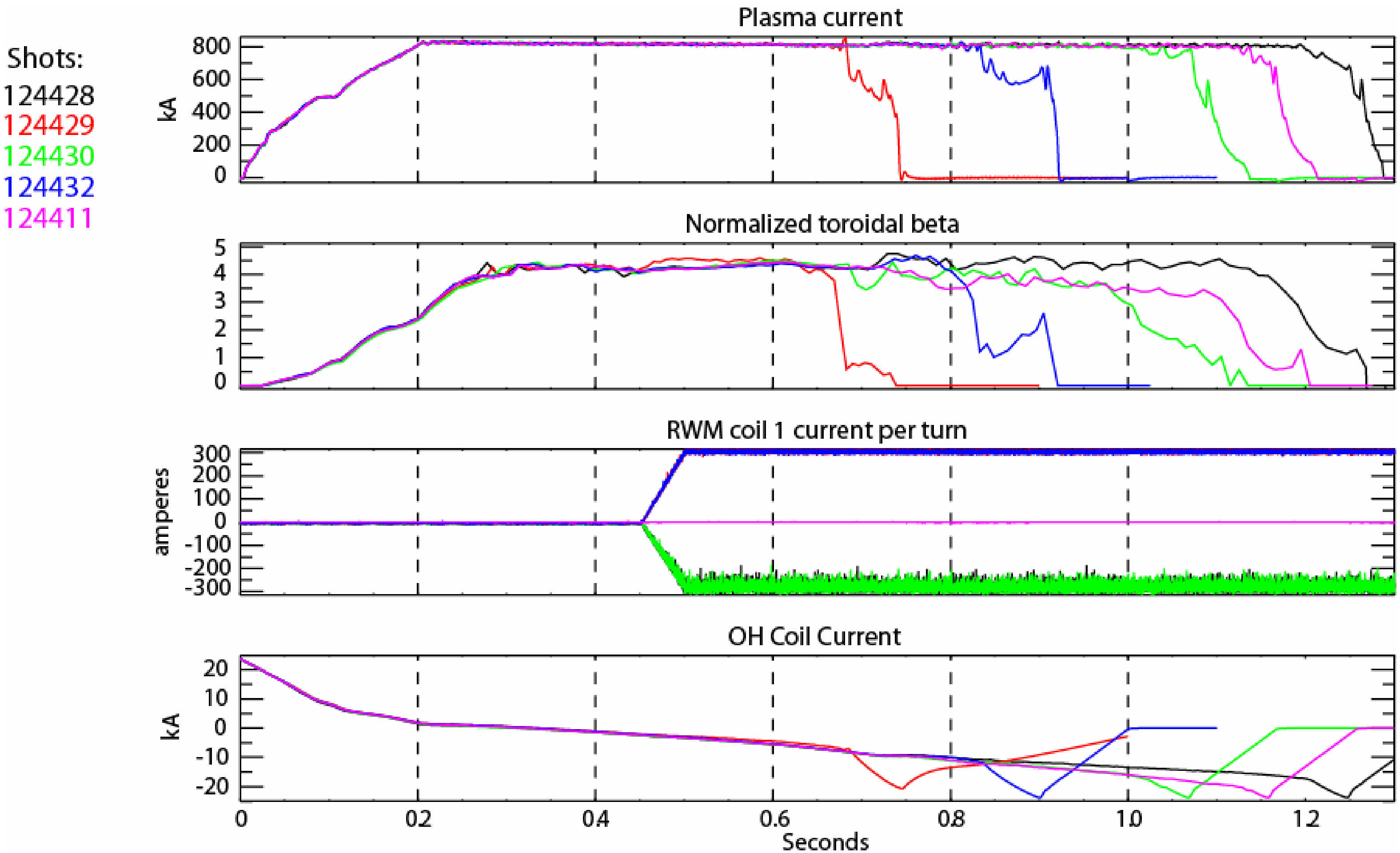
- Rotation collapse begins at t=0.45s, and is most clearly evident for radial positions R > 1.25m





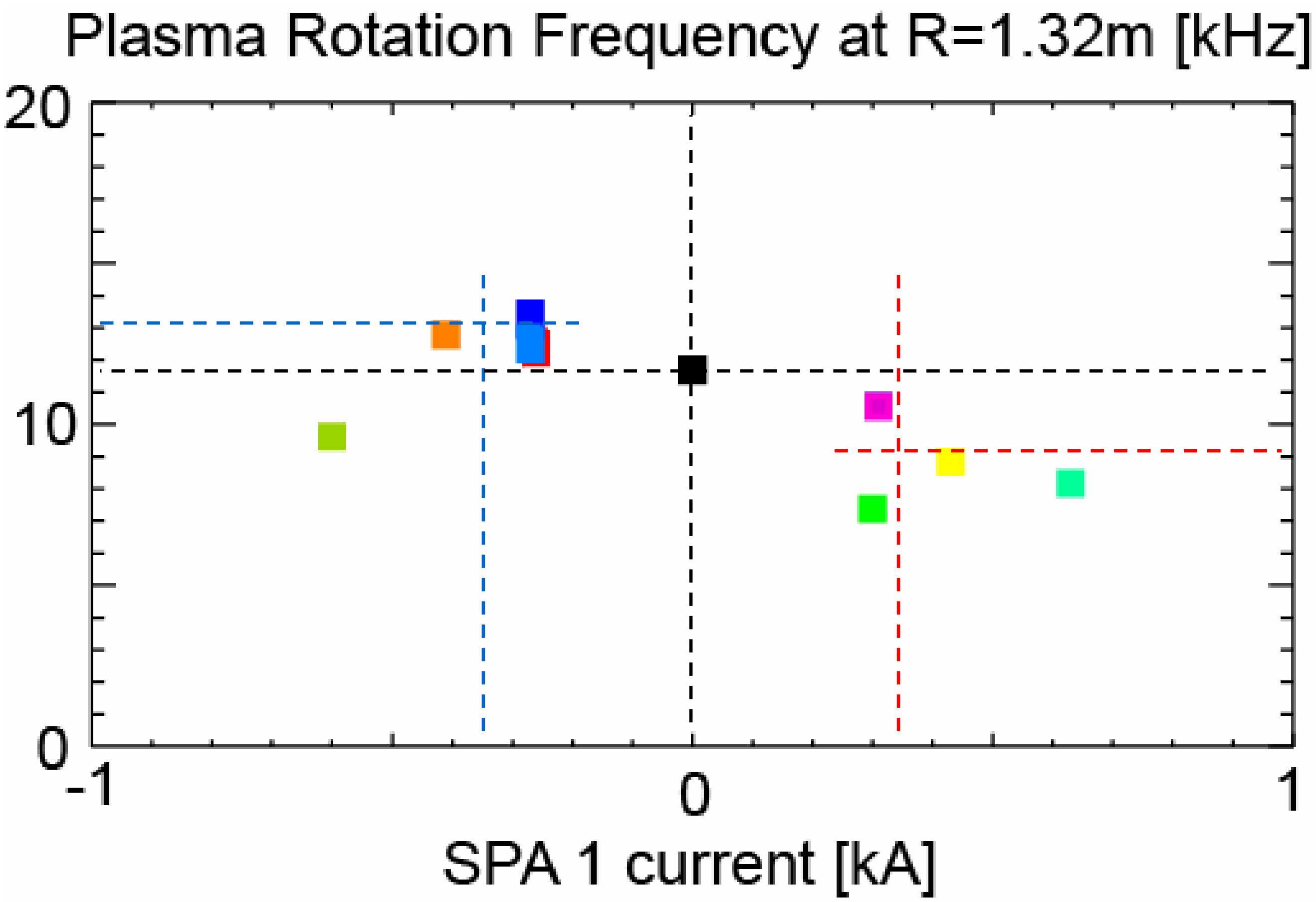
NEW: Plasma exhibits asymmetric response to applied n=3 field

- Pulse-length depends on polarity of applied n=3 field



Outboard Ω_ϕ changes by 30-40% with n=3 polarity flip

- Optimal n=3 current magnitude = 300-400A
- PF5 coil shape data from 2004 → PF5 is source of n=3 EF
  - Need to assess if this is consistent with empirical correction below



XP702 - RFA detection optimization during dynamic error field correction

- Implemented real-time mode-ID using U+L B_P and B_R sensors
- Compared DEFC response using upper and lower B_P sensors vs. just using upper B_P sensors (as was used in 2006)
  - More robust mode-ID achieved (higher signal / baseline offset)
  - Higher proportional gain possible (0.7-0.8 vs. 0.5)
- Could not reproduce 2006 reference discharge which previously exhibited intrinsic rotation collapse →
  - Instead, applied n=1 EF pulse to induce collapse when OHxTF small
  - Scanned DEFC phase and gain until applied currents were nulled

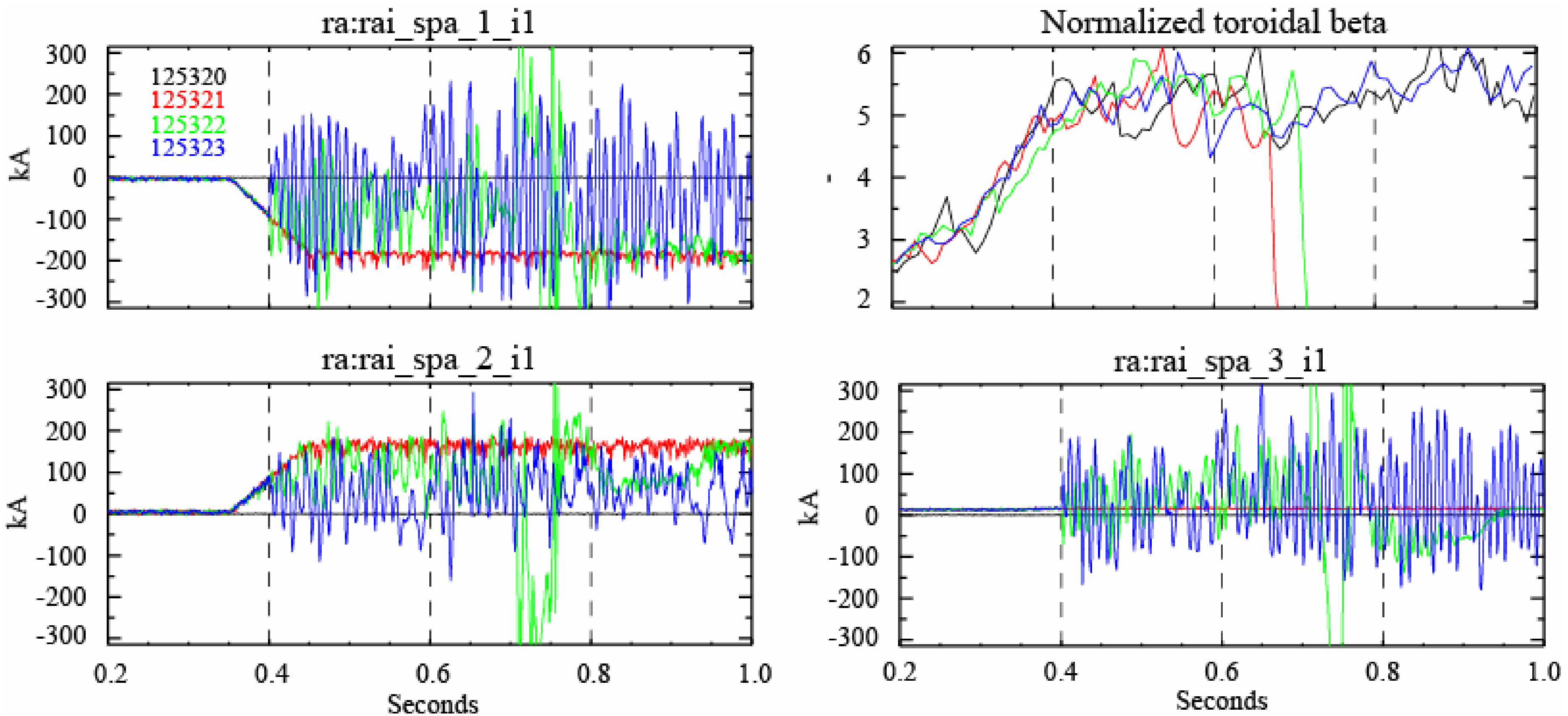
  → **feedback system "trained" to eliminate EFA of known source**
- Combination of "trained" n=1 DEFC + n=3 EFC →
  - longest pulse of all shots in XP702
  - sustained plasma rotation

DEFC system trained to null RFA from externally applied/known n=1 error field source

NSTX

- Optimal phase difference (δ=270°) between measured B_P (U/L avg) and applied B_R required to null n=1 EF pulse
- Sufficient feedback gain also required:

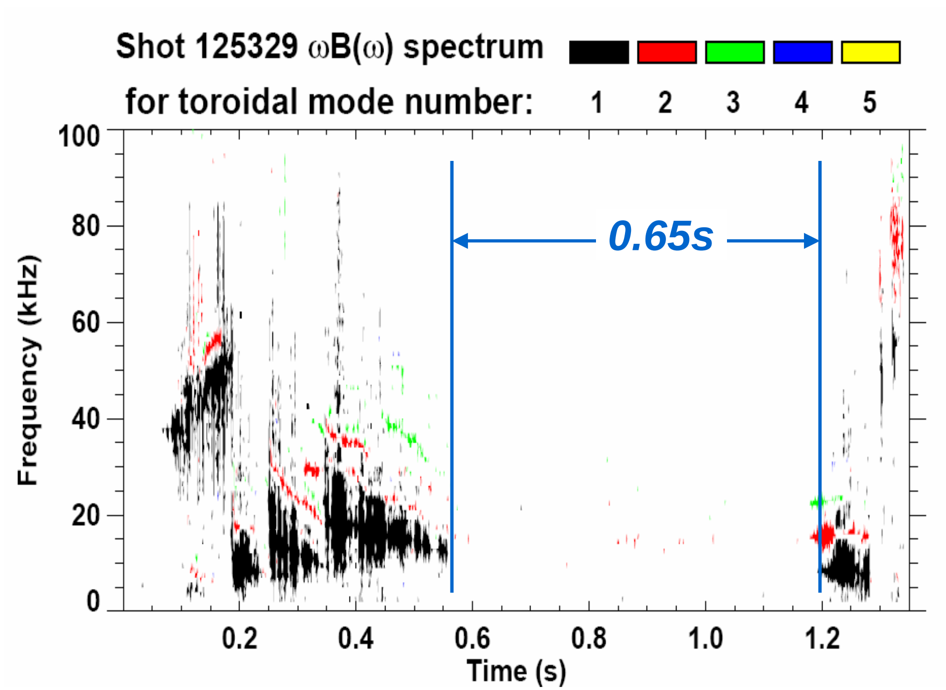
G_P=0.0 G_P=0.5 G_P=0.7

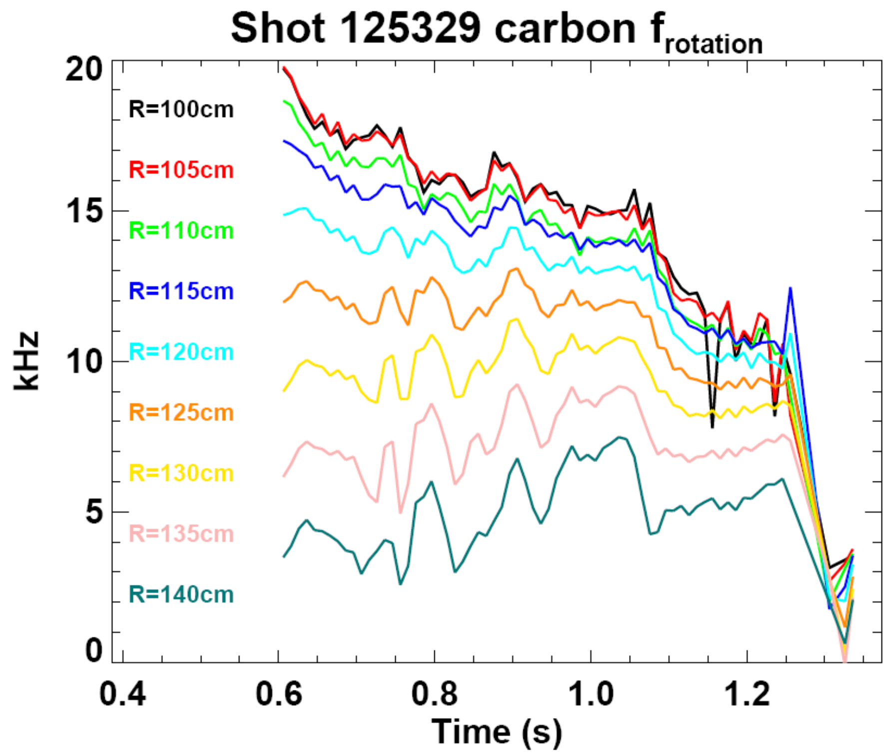


n=1 RFA feedback + n=3 EFC improves performance

- Long period free of core low-f MHD activity
- Plasma rotation sustained over same period
  - Core rotation decreases with increasing f_{GW} → 0.75, P_{RAD} → 3.5MW
  - R > 1.2m rotation slowly increases until t=1.1s (large ELM?)

→ Longest pulse at I_P=900kA





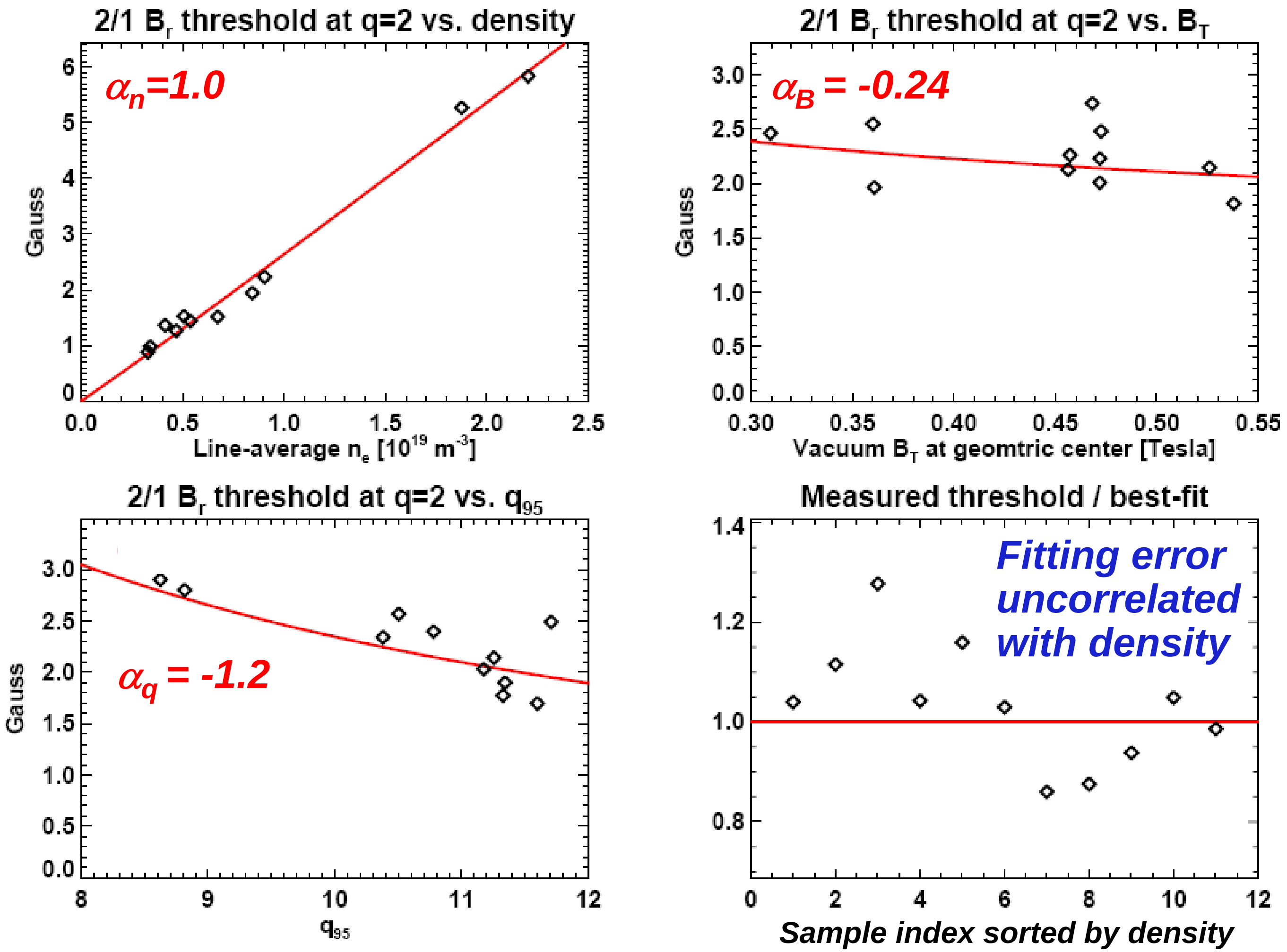
XP703 - B and q scaling of low-density locked-mode threshold at low-A

- Extended density range for threshold – now have factor of 4
- Performed B_T scan from 3kG to 5.5kG
- q_{95} scan difficult because high-q does not have q=2 in plasma
  - Found this out after MSE data was obtained
- Threshold increases with increased edge q-shear (w/o MSE)
  - Similarly - also increases with internal inductance
- Obtained MSE data for 4 scenarios of interest
  - q=2 surface is in plasma at time of locking, but NO q=1 surface
  - Core shear is often weakly reversed
  - Measured q profiles not yet included in analysis shown below!
- Locking threshold scaling favorable for ITER

NOTE: Scaling form used below: $B_{21}(\text{lock}) \propto n^{\alpha_n} B_T^{\alpha_B} q^{\alpha_q} R^{\alpha_R}$

NSTX locking data shows linear density scaling and weak B_T dependence, but unexpected inverse scaling with q_{95}

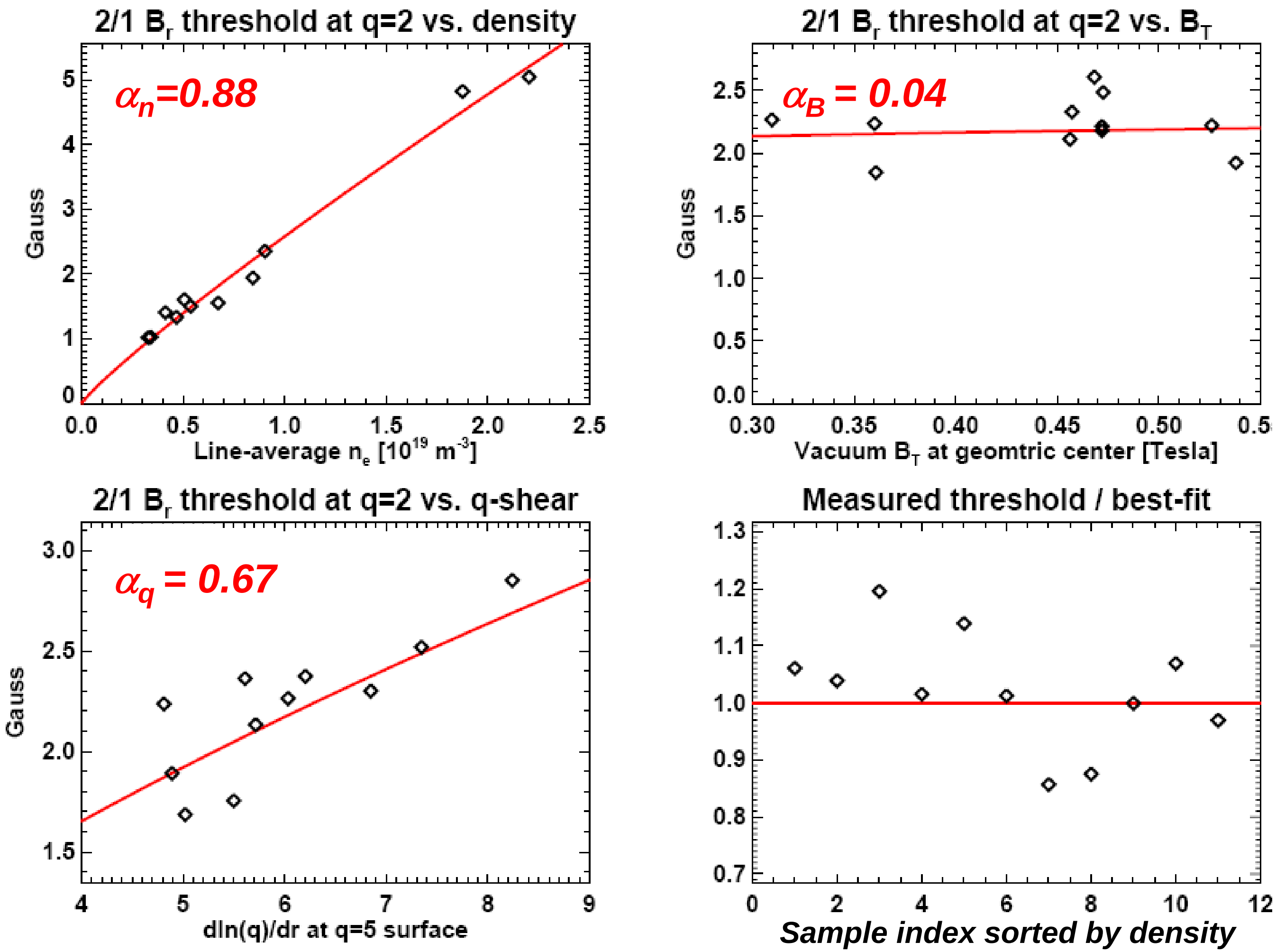
2/1 B_r



MSE data (not used for scaling above) shows variation in q_{min} when q_{95} is varied.
q(0) does not = 1 as for other experiments → q_{95} not good proxy for q-shear for NSTX.

NSTX locking data shows nearly linear density scaling and very weak B_T dependence, and expected positive scaling with edge q-shear

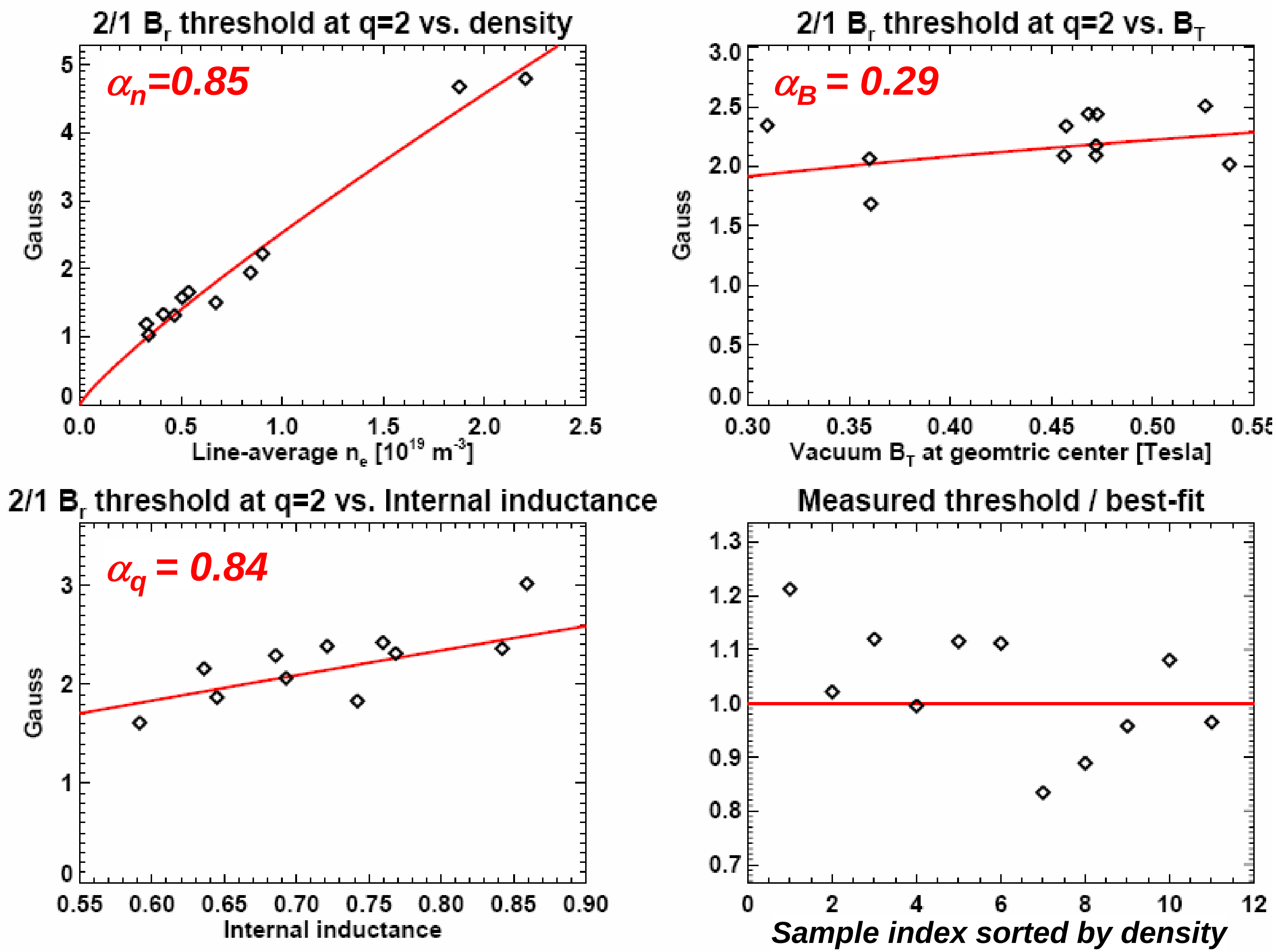
2/1 B_r



Density and B-field scalings are sensitive to choice of q-scaling variable, but, assuming size scaling coefficient $\alpha_R = 2\alpha_n + 1.25(\alpha_B - 1) \rightarrow$ NSTX α_R = 0.45 to 0.56

NSTX locking data shows nearly linear density scaling, weak positive B_T dependence, and nearly linear scaling with internal inductance

2/1 B_r



Density and B-field scalings are sensitive to choice of q-scaling variable:

Range in NSTX: α_R = 0.45 (q_{95}), α_R = 0.56 (q′ at q=5), α_R = 0.8 (l_i)

Large extrapolation from NSTX to ITER, but here it is…

For NSTX q_{95} scaling with:

$n_e=10^{19}m^{-3}$, $B_T=5.7T$, $R_0=6m$, $\alpha_R = 0.45$, $q_{95}=3$

ITER $B_{21} \rightarrow$ 14G, or $B_{21}/B_T = 2.5x10^{-4}$

For NSTX l_i scaling with:

$n_e=10^{19}m^{-3}$, $B_T=5.7T$, $R_0=6m$, $\alpha_R = 0.8$, $l_i=1.0$

ITER $B_{21} \rightarrow$ 30G, or $B_{21}/B_T = 5.2x10^{-4}$

Caution – no q=1 surface in NSTX plasmas which could lower thresholds in ITER (and NSTX)

Also need to propagate uncertainties through analysis properly…

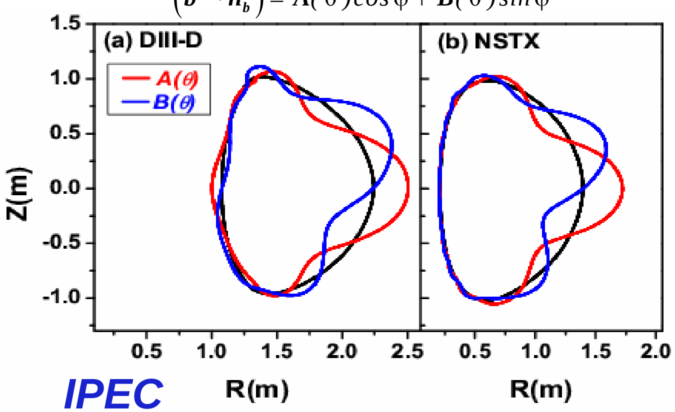
IPEC analysis not yet systematically included in scalings

- IPEC analysis shows that total $B_\perp^{mn}$ (including plasma response) on resonant surfaces differs significantly from vacuum external $B_\perp^{mn}$
  - So how did we account for intrinsic error field in NSTX if plasma response is important, and we didn't include it?
- Empirically find that different normalization for $B_\perp^{mn}$ can improve accounting for EF using only vacuum fields:
  - Instead use perturbed helical flux: $$\delta\psi^h_{mn} = \sigma\left[R^3 \left|\frac{q}{F}\right| (B_Z \delta B_R - B_R \delta B_Z) \right]_{mn}$$

Where σ is a polarity and phase factor and $F = B_\phi R$

  - $\delta\psi^h$ scales as $\mathbf{R^2}\ |\nabla\psi|\ q/F\ B_\perp^{mn}$

$$\left(\vec{b}^x \cdot \hat{n}_b\right) = A(\theta)\cos\varphi + B(\theta)\sin\varphi$$



IPEC

R^2 scaling of $\delta\psi^h$ apparently provides better geometric representation of fields that generate singular currents, torques, and mode locking

ALL NSTX DATA SHOWN ABOVE USES RENORMALIZED VACUUM $\delta\psi^h$ to compute $\delta B_{2/1}$