SPARC 3D Field Physics and Support of the Non-Axisymmetric Coil Assessment

INFUSE Workshop 2021

Alex Creely (CFS)

Nikolas Logan (LLNL)

Carlos Paz-Soldan (Columbia)

Ryan Sweeney (MIT)

Motivation

- Tokamak plasmas resonate with certain 3D fields in ways that generally degrades plasma confinement
- The fields that greatly reduce confinement and even terminate the plasma are called Error Fields (EFs)
  - Caused by non-idealities in tokamak magnets introduced during design (winding pattern), manufacturing (saddle and ellipticity), and assembly (tilts and shifts)
- Sometimes mild degradation is desired to stabilize Edge-Localized-Modes (ELMs), and these fields are called Resonant Magnetic Perturbations (RMPs)
  - All 3D fields can brake the plasma rotation, so the RMP must be applied efficiently
- There are many *possible* coil solutions to correct EFs and apply RMPs, so finding an *optimum* solution is challenging

Program overview

Technical Goals

- Identify dominant Error Field spectra for core and edge resonances as well as core and edge NTV torque
- Identify dominant Error Field sources and associated correction coil requirements
- Identify and compare 3D coil designs optimized to meet said requirements
- Assess 3D coil designs’ ability to suppress ELMs while avoiding core locking events

Program Schedule

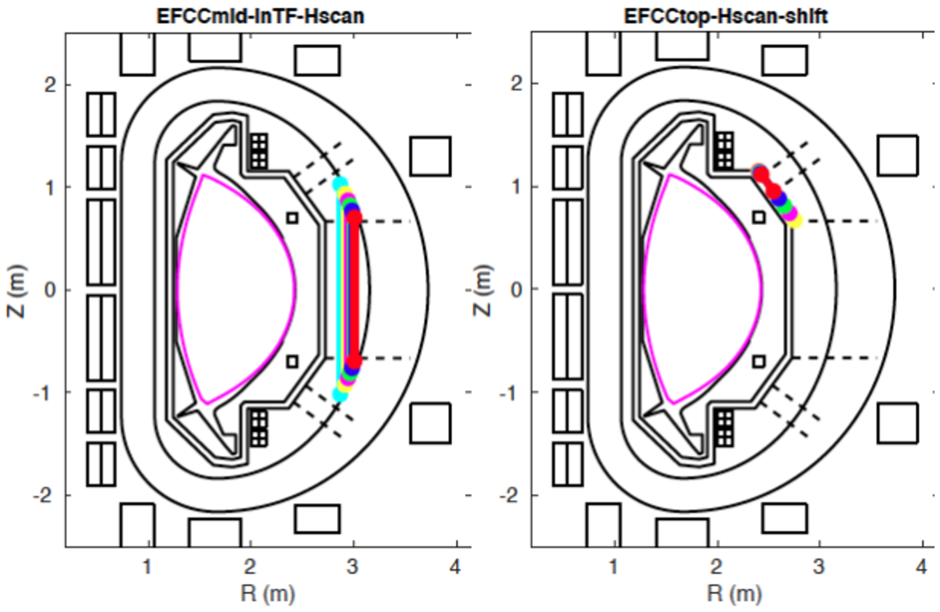
- Performance period: 12/04/2020 – 12/04/2021

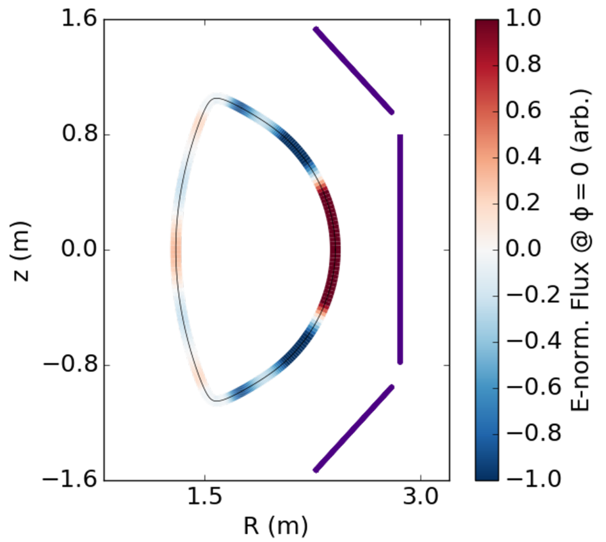
Phases	‘20	‘21			
	Q4	Q1	Q2	Q3	Q4
Assessment of Conceptual Design Space					
Detailed Assessment of Conceptual Design					
Assessment of Proposed Changes for Preliminary Design					

Program successfully accomplished all technical goals

Identification of dominant spectra helped guide 3D coil geometry decisions

- Linear, ideal MHD can identify most amplified mode, presumed to dominate the error field (EF) physics
  - Dangerous EF is the part that "overlaps" with this mode
- Many coil geometries were explored for SPARC
  - Each evaluated by how much the field it produced overlapped with the identified dominant mode
- Dominant mode has long wavelength & high amplitude on on the low field side → build coils there
  - Compatible with engineering constraints ✔

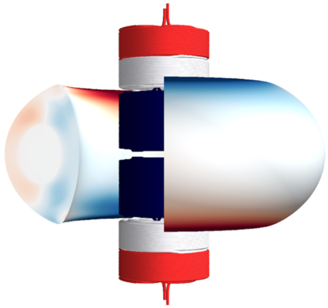




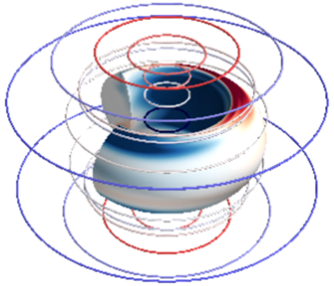
Statistical approach used to identify EF sources and associated correction coil requirements

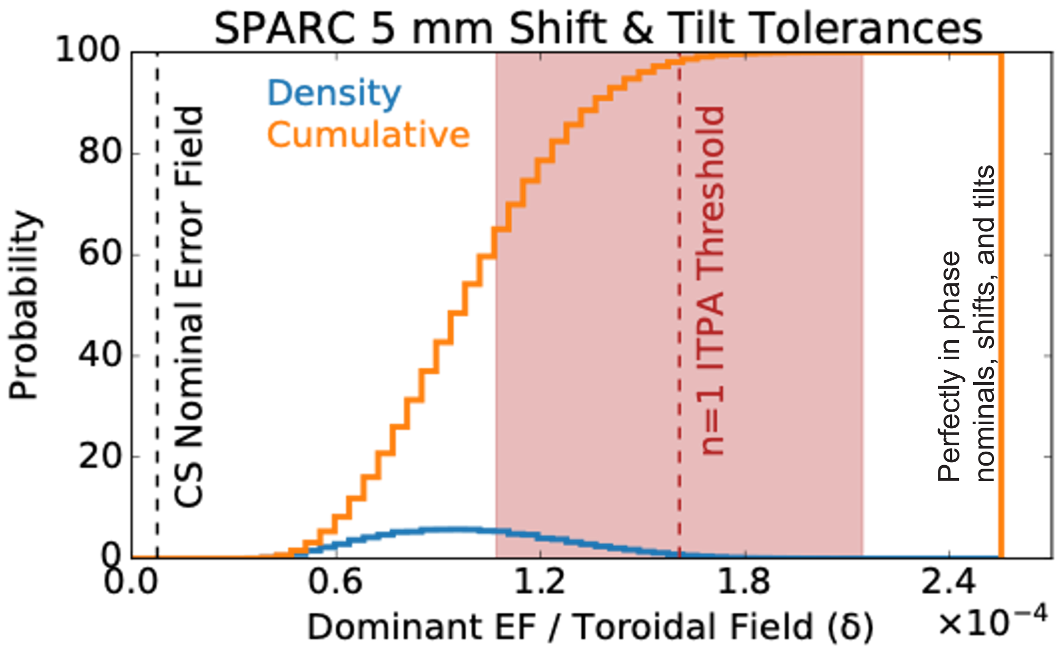
- Even nominal designs can have significant amounts of error fields from windings/leads/etc.
    - Optimizing windings and relative “clocking” of coils to minimize nominal error fields
    - Care taken to avoiding inboard errors, which would be hard to correct with outboard EFCCs
- Monte Carlo of shifts & tilts provides statistical expectation of eventual EF for given tolerances

Nominal Windings



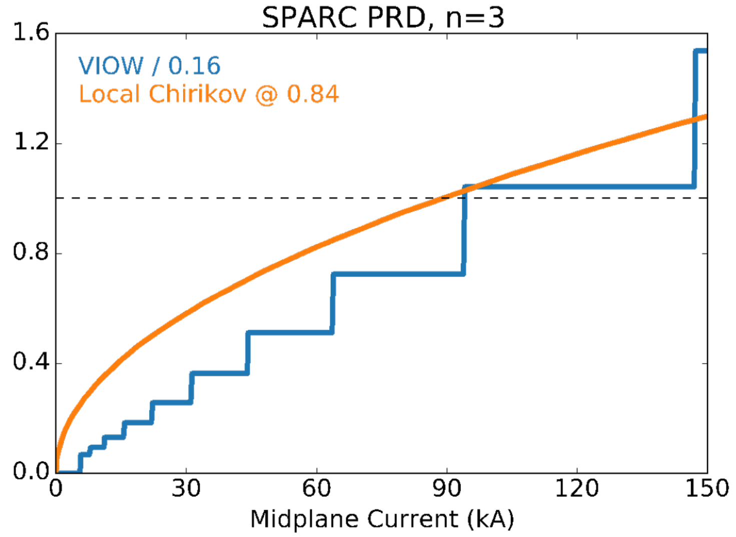
Tilts & Shifts

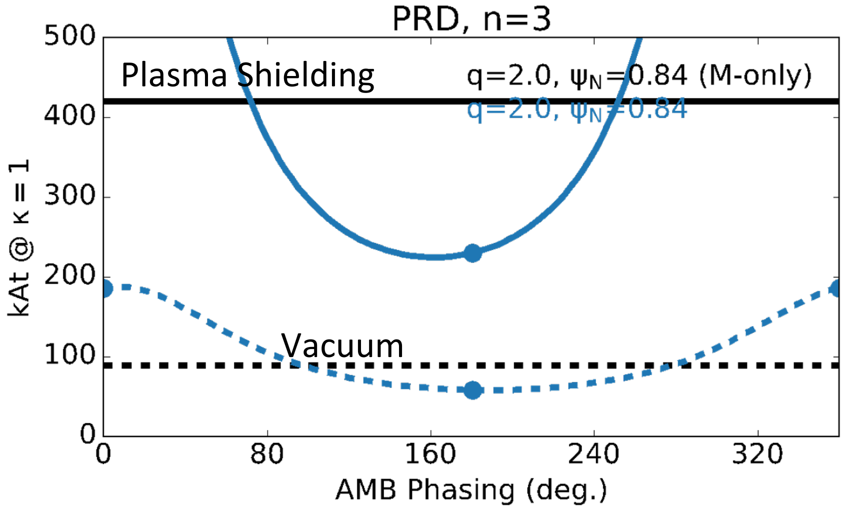




Resonant magnetic perturbations (RMPs) assessed for edge-localized-mode (ELM) suppression

- Used published vacuum criteria to set coil current requirements (like ITER)
  - Vacuum Island Overlap Width VIOW > 0.16, validated in DIII-D [1]
  - Local Chirikov $\kappa>1$ at $\psi_N=0.84$ also used (smooth √I dependence guides assessment of safety margins)
- n=3 targeted to avoid core tearing & utilize wealth of experience on existing machines
  - Dominant mode has shorter wavelength → phasing of multiple rows used to twist RMP appropriately
- Open questions identified: Is ELM suppression possible in strong SPARC shaping where plasma shields RMPs?
  - This will be answered during early SPARC operation

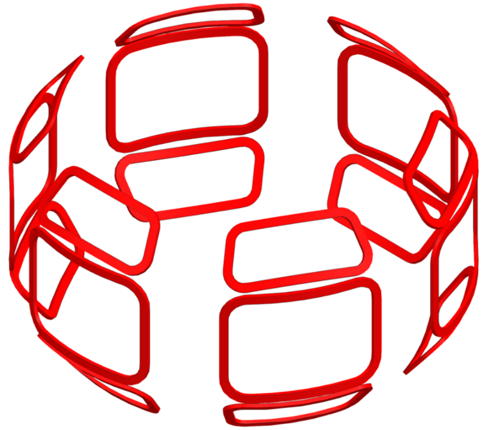




[1] Fenstermacher, Phys. Plasmas 2008

INFUSE produced instructive & practical guidance for SPARC designs

- Quickly delivered guidance to conceptual design review
- Provided detailed design assessments at a pace consistent with CFS' needs
  - Prompt responses to quickly evolving design cycles
  - Provided guidance on:
    - How to formulate the *SPARC General Requirements* on error fields
    - How to choose the best toroidal periodicity for the RMP
    - Coil wiring schemes and power supply requirements
- The physics guidance together with engineering converged on a coil set ready for the Preliminary Design Review



INFUSE Programs on the SPARC Timeline

SPARC

Divertor Component Testing
Oak Ridge National Laboratory

Divertor Plasma Simulations
Lawrence Livermore National Laboratory

SPARC 3D Field Physics
Lawrence Livermore National Laboratory

Divertor CDR

Materials Downselect

Plasma Facing Components PDR

Error Field Correction Coil PDR

2020	2021	2022	2023	2024	2025

Toroidal Field CDR

Central Solenoid CDR

Limiter CDR

Central Solenoid Model Coil PDR

Central Solenoid PDR

SPARC commissioned

Alpha Particle Diagnostics
PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Superconducting Cable AC Loss and Quench Detection
BROOKHAVEN NATIONAL LABORATORY