Alpha Particle Loss Assessments and Status of Coil Optimization for 2 Field-Period CS

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2-field period CS can simplify reactor core maintenance

- The most developed CS configuration is the 3-field-period case (18 coils), which is modeled after NCSX and scaled by the systems code to produce 2 GW of fusion power, consistent with blanket/shield requirements.

- The 2-field-period candidate is developed with the motivation to allow for simple sector maintenance, with a smaller number of modular coils.

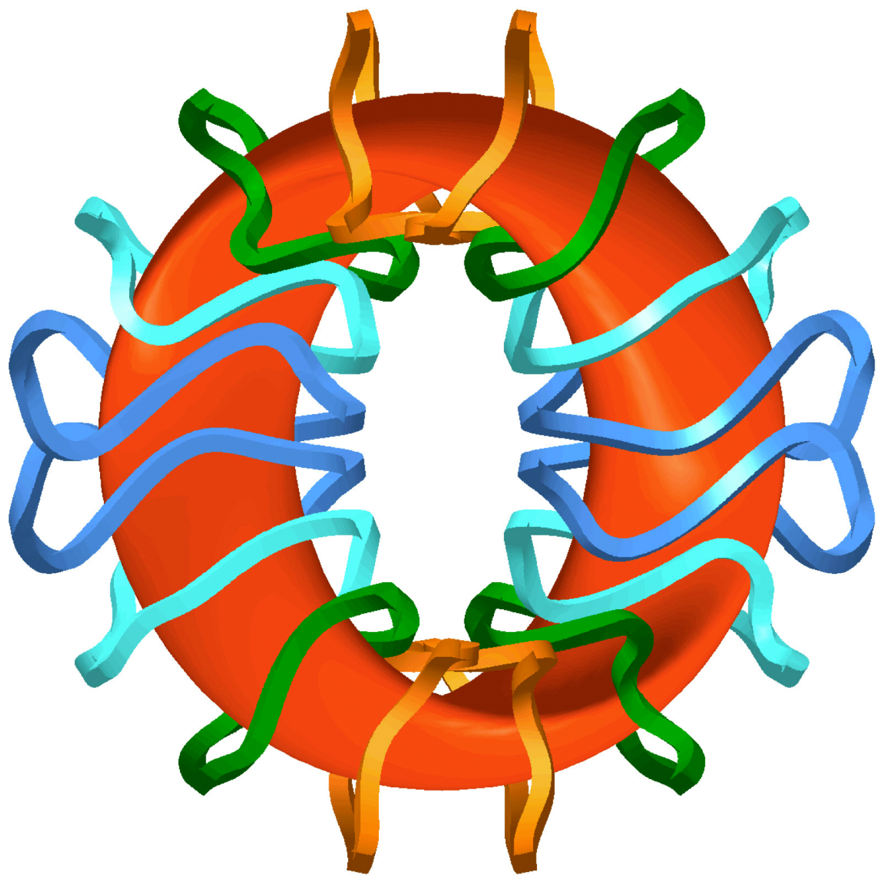
  Presently, there are two versions: 16 coils and 12 coils.

  Detailed evaluation is on-going to reach a self-consistent configuration.

- In this talk, we will focus on the issue of □ particle loss for the 2 fp 16-coil configuration.

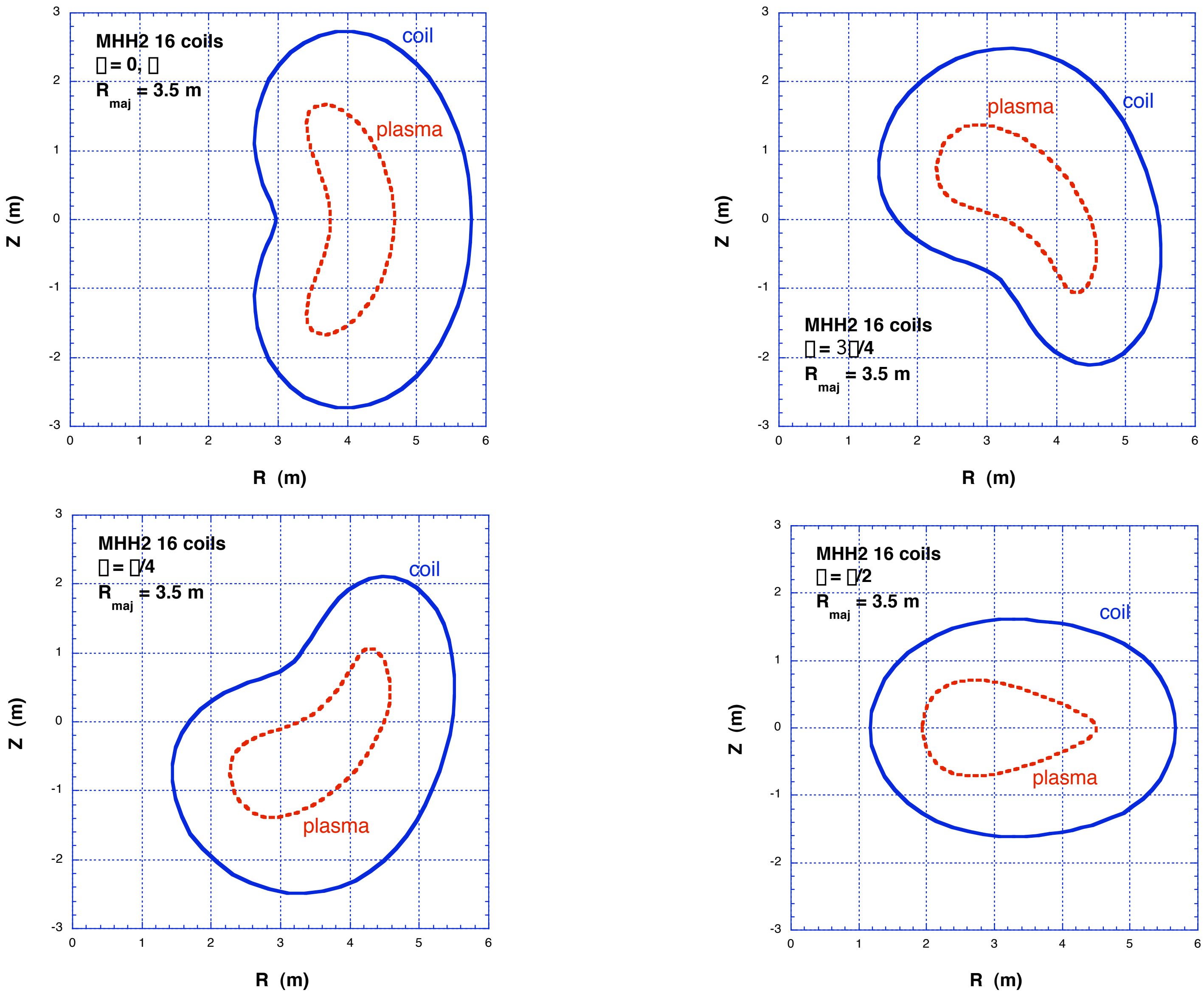
Parameters for the MHH2 16-coil CS Candidate

Number of field periods	2
Number of coils	16
$\square_{c-p}$ (m)	1.38
$\square_{c-c}$ (m)	0.56
Coil Cross Section (cm x cm)	40 x40
Coil current (MA)	12.4
<R> (m)	7.5
<a> (m)	2.0
Aspect ratio	3.75
$\square$ (%)	4.0
V_p (m^3)	595
S (m^2)	732
B_o (T)	5.0
B_{max} (T)	14.36
<j> (kA/cm2)	7.76



Top View

Plasma and coil-winding surfaces for MHH2 16-coil CS



Alpha Particle Confinement in a CS Configuration

- α particle confinement can be important in several ways:

  - It affects the plasma power balance and the reactor plasma operating point.

  - It can contribute significantly to the divertor heat load, and dictate how the divertor is designed

    # profile of heat load (peak-to-average)

    # blistering of divertor coating due to certain lost α incident angles and energy spectrum

- In this work, we will assess the heat flux due to lost α's at the LCMS for the present MHH2 16-coil configuration. This provides a starting point for addressing the divertor issue.

The ORBIT-3D Particle Trajectory Code

(R.B. White, PPPL)

- This code uses a Hamiltonian guiding center drift orbit formalism to calculate particle trajectories in magnetic field configurations of arbitrary cross section with arbitrary plasma β.

- It is coupled to a 3-D equilibrium geometry, generated by VMEC.

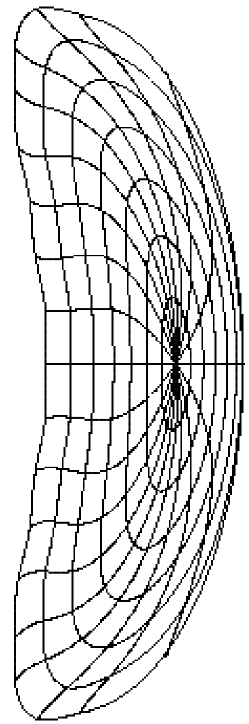
- The straight field line (Boozer) coordinates are used, in which the magnetic field is given as a Fourier series:

$$B(\vec{r}) = \sum_{m,n} B_{mn}(s)\cos(m\theta_b - n\phi_b)$$

where the n≠0 coefficients are the non-axisymmetric components.

- In our calculations, we assume the equilibrium to consist of closed nested flux surfaces, i.e., no island.

Plasma Equilibrium and Assumed Plasma Parameters



- A VMEC equilibrium closely approximating nominal MHH2 16-coil case is generated (by L.P. Ku), that assumes

  $$p(s) \sim (1 - s^{1.5})^{1.5}$$

  $$\beta = 4\%$$

  There is no net current in the plasma.

- It assumes $B_o = 5.5$ T, $R = 7.5$ m, and
  $n_e = n_i = 1.3 \times 10^{14} \; (1 - s^2) \; \mathrm{cm}^{-3}$
  $T_e = T_i = 11.5 \; (1 - s^2) \; \mathrm{keV}$

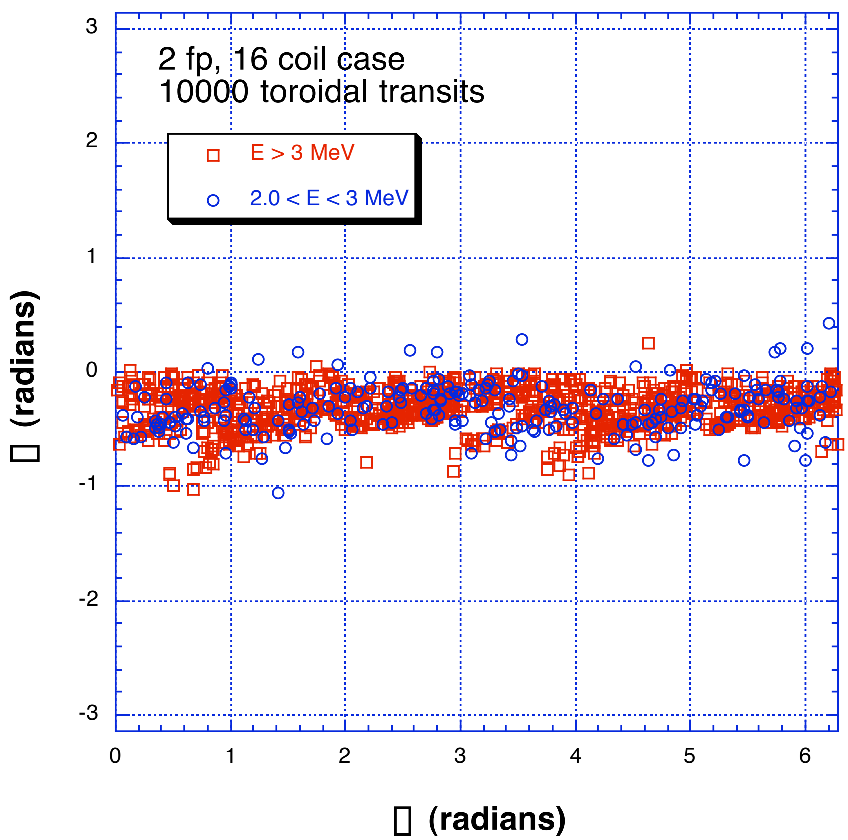
  Initial $n_\alpha \sim (1 - s)^8$

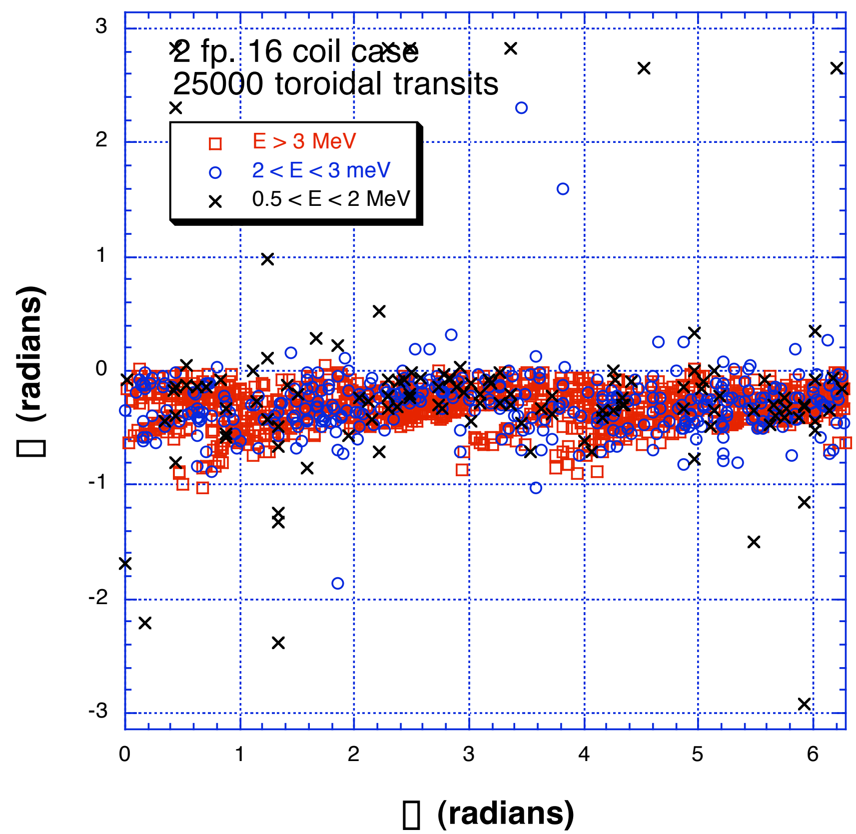
- The sample size used is 4000 particles.
  Particles are collisionless and slow down on the background plasma.
  Lost particles are not replaced.

Lost Alpha Footprint on LCMS During the Early Stages

- Average toroidal transit time is 3.6 □s
- During the early stage, energetic □'s (2-3 MeV) dominate the loss.
  The losses are concentrated along a toroidal strip with $-0.5 < □_b < 0$

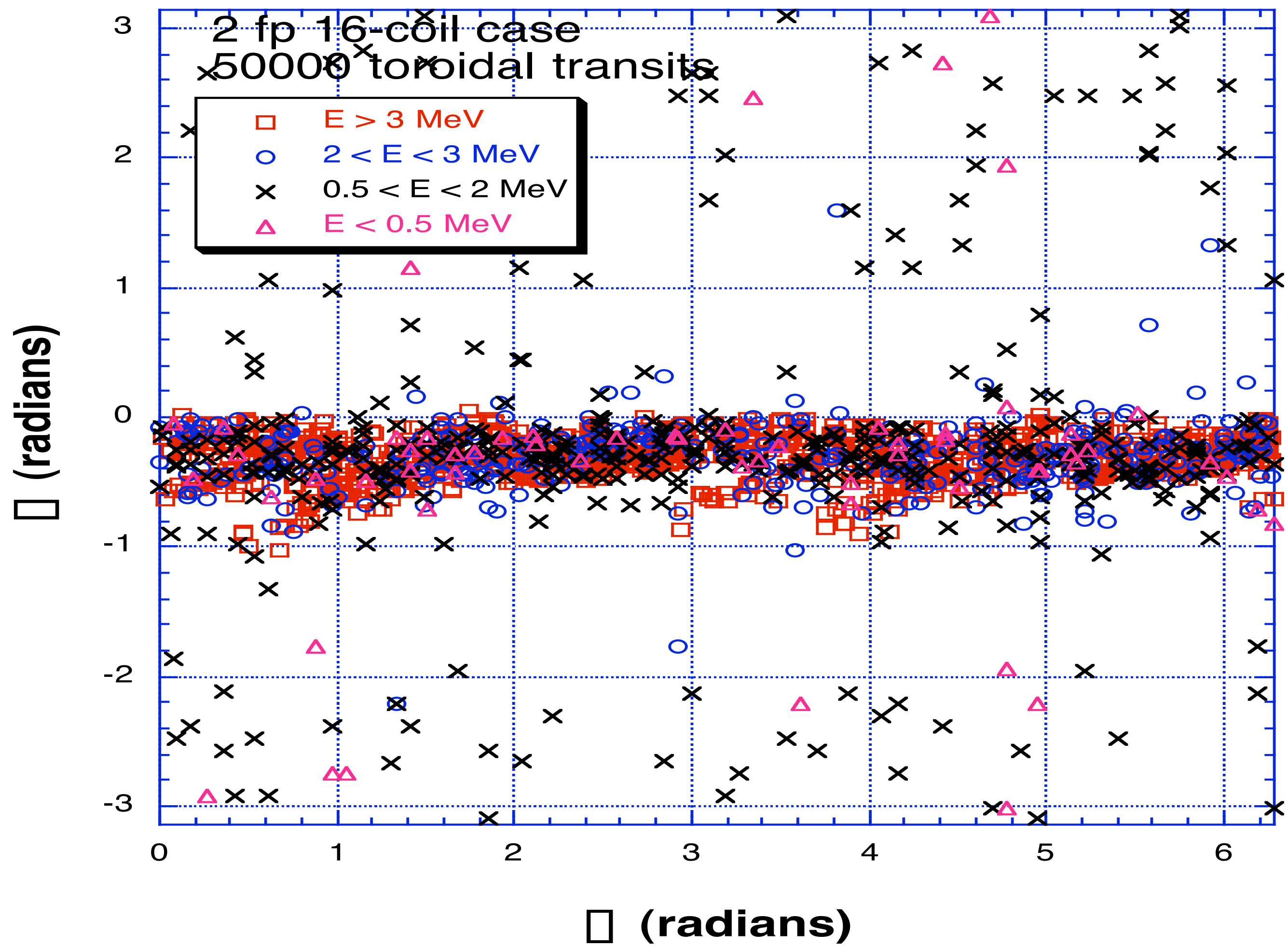
Note: □, □ in the figures are Boozer coordinates





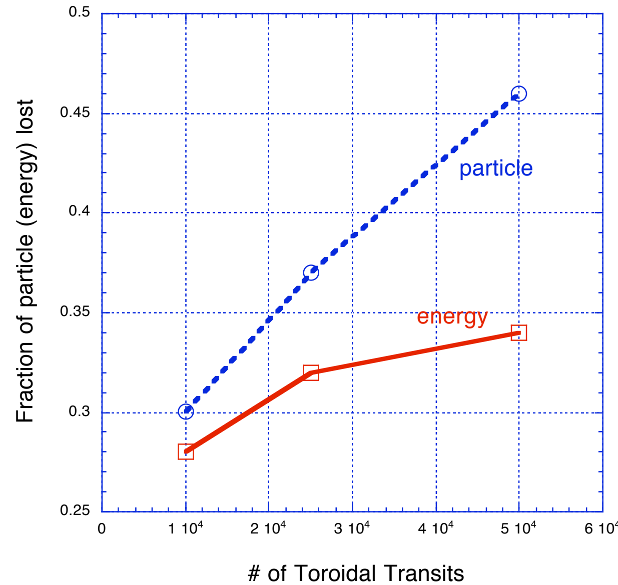
More Lower Energy □'s are Lost at Later Stages (t = 0.18 s)

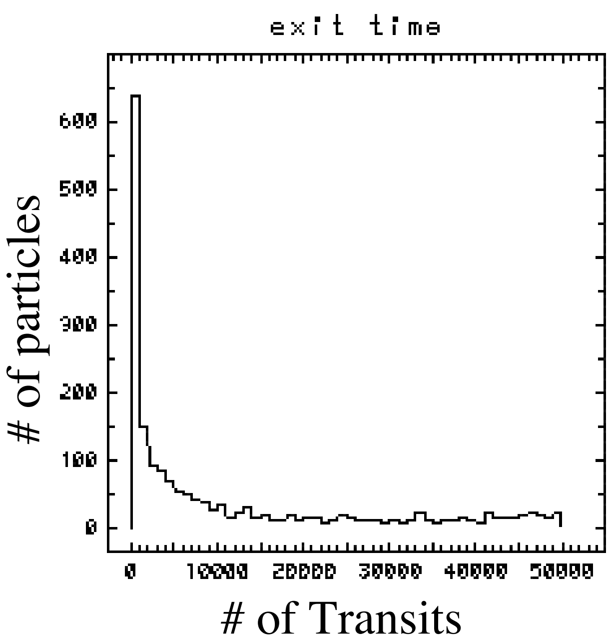
- Particles are lost uniformly along the toroidal direction, with a weakly discernable periodic structure of the footprint.

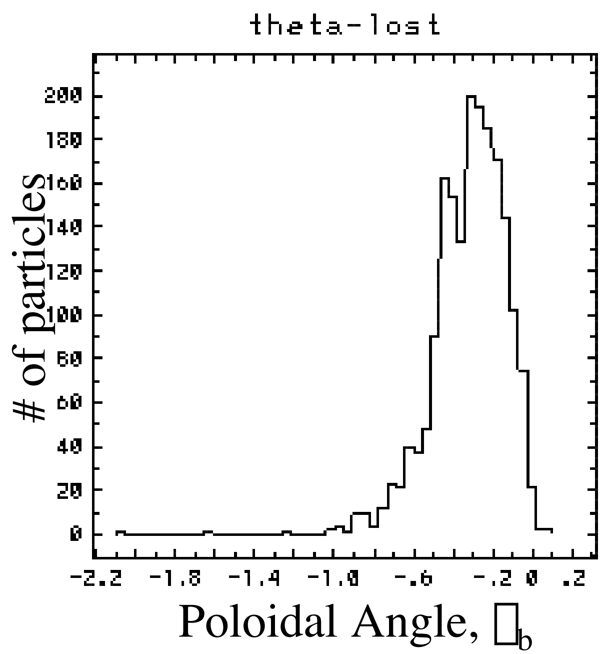


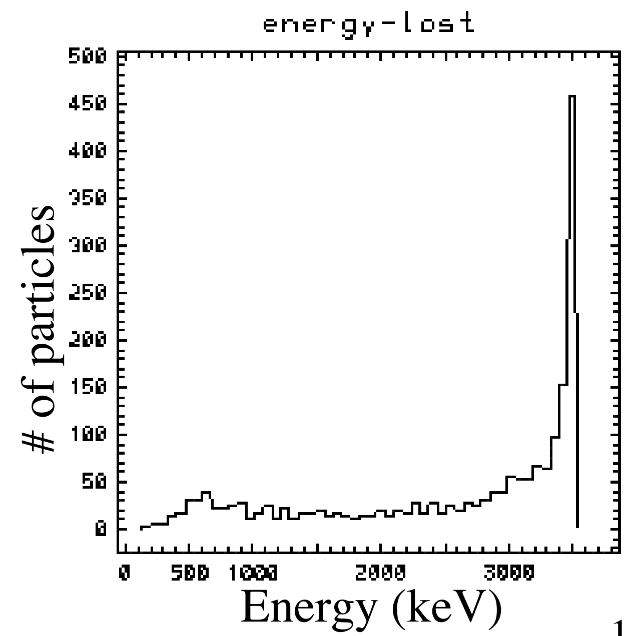
A Summary of ORBIT3D Results at 50000 Transits

- It appears that a large number of α's are born on "bad" orbits leading to prompt or very early loss from the plasma, contributing to a large fraction of energy lost. This can be reduced by improving the QA of the plasma and by other means to prolong the α residence time (L.P. Ku).
- The particle loss is localized at OB region below the equatorial plane.





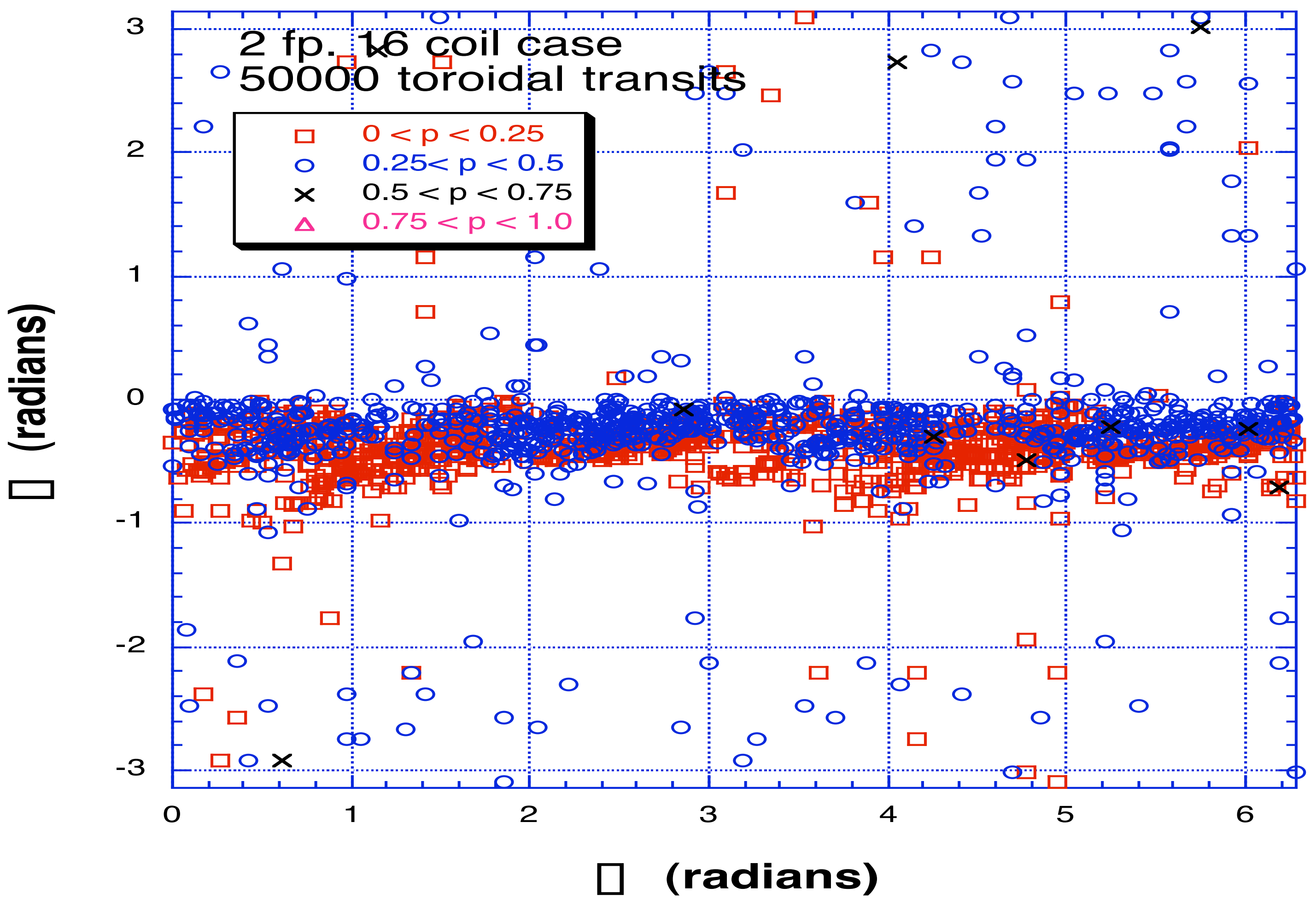




Pitch Distribution of Lost Particles Indicates Trapped Orbits

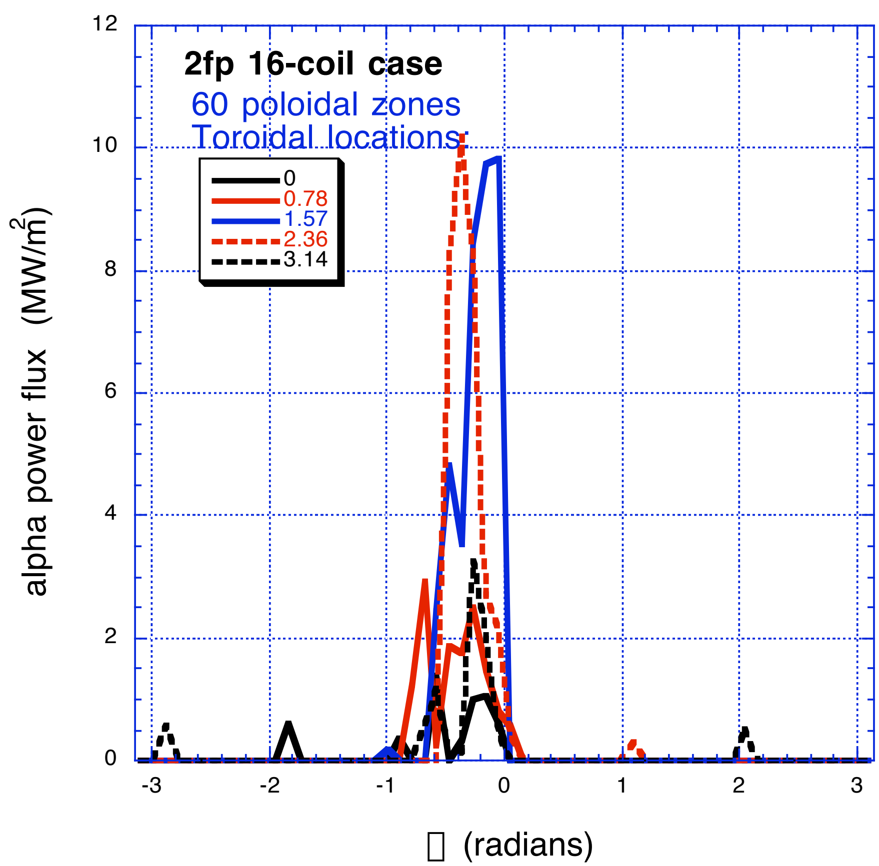
- Pitch : $p = | v_{||} | / v$

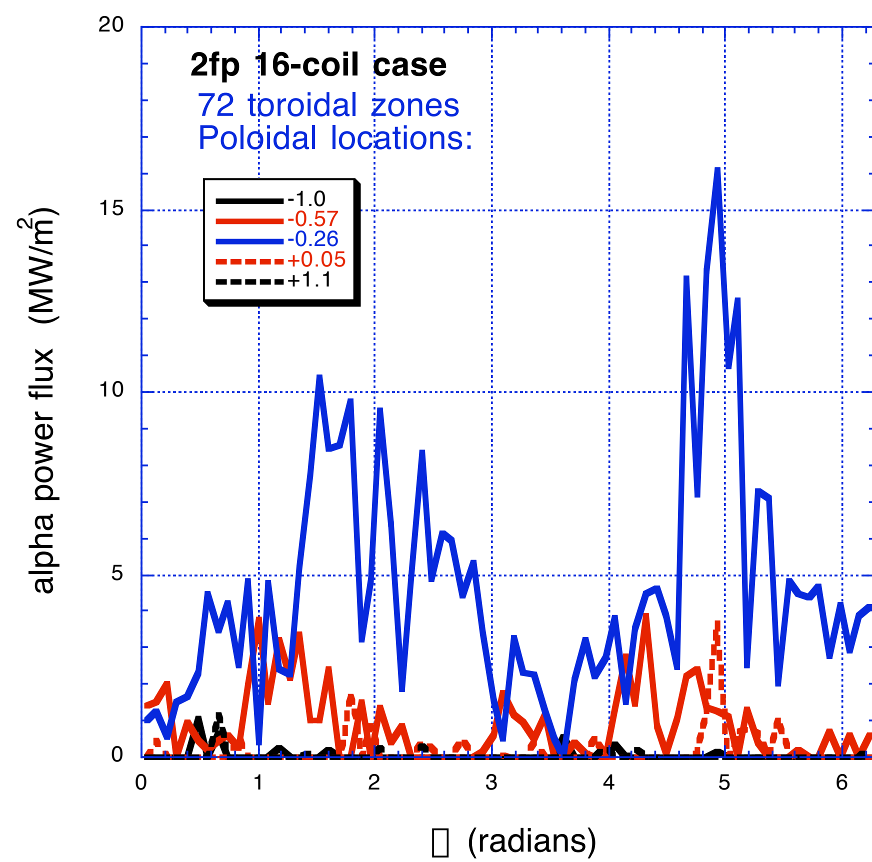
Most particles lost have $p < 0.5$.



Estimate of Heat Load on LCMS due to Lost Alphas

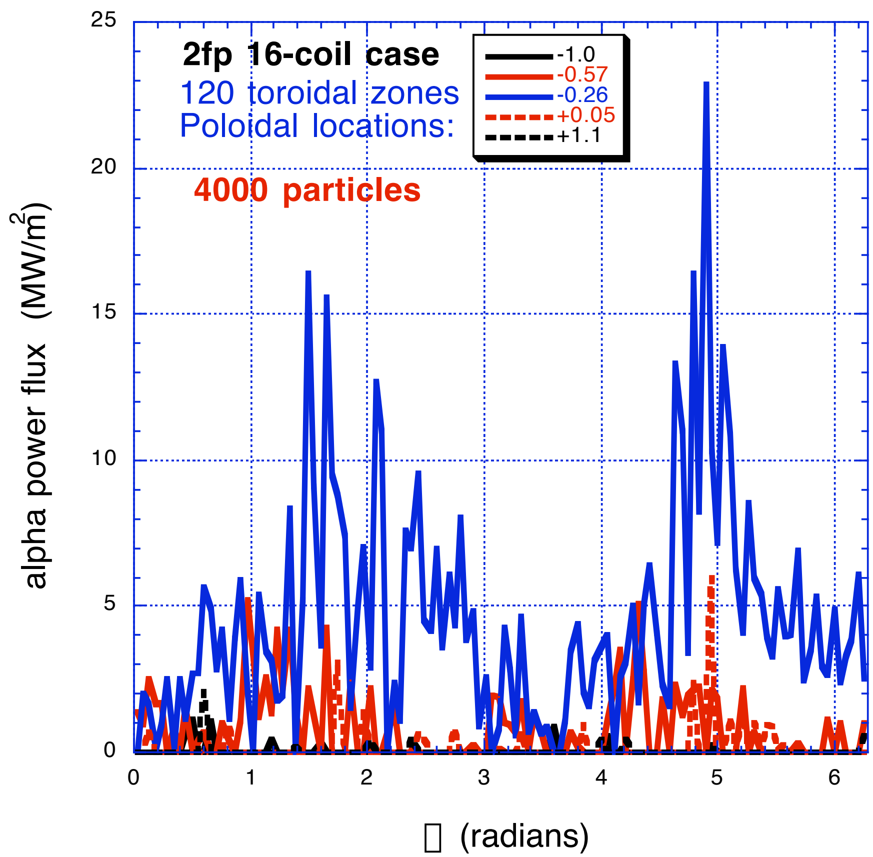
- For now, we make the assumption: $□_b \approx □$(configuration) [?]
- We divide the plasma surface into rectangular segments, and add up the energy collected in each segment. For P_{fus} ~ 2000 MW, $P_□$ ~ 400 MW, and total power to surface is $f_{□L}\ P_□$ where $f_{□L}$ is fraction of □ energy lost. Heat load to segment: $W_□ = f_{□L}\ P_□\ □\ (□E/E_{tot})$/Area

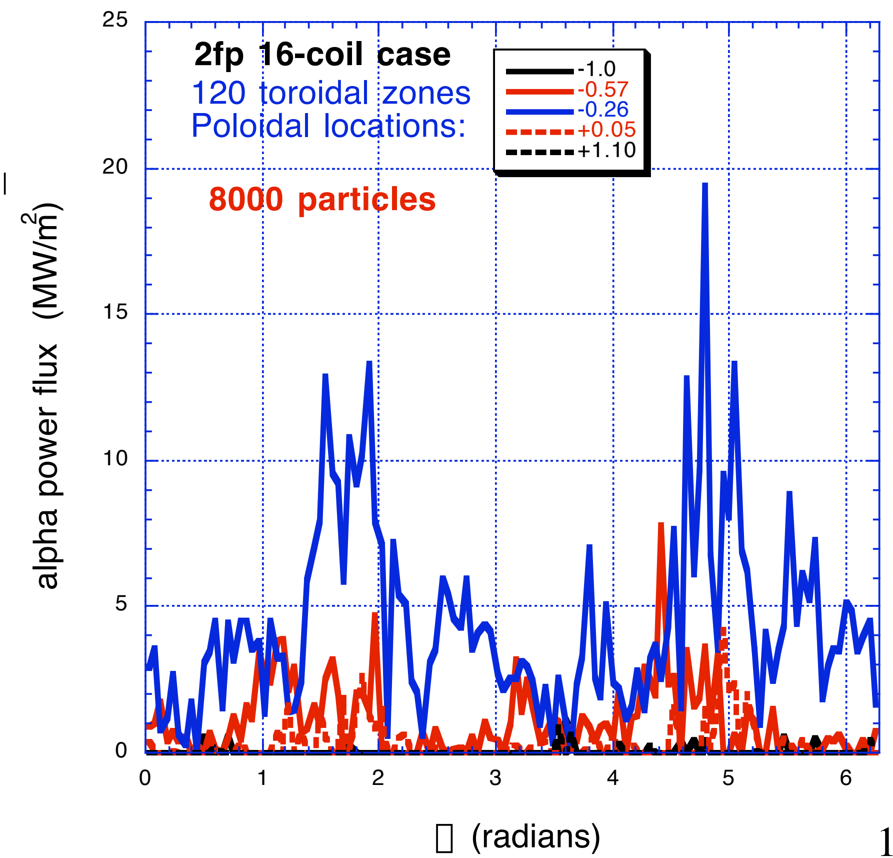




Heat Load Distribution is Sensitive to Number of Particles And Number of Surface Segments

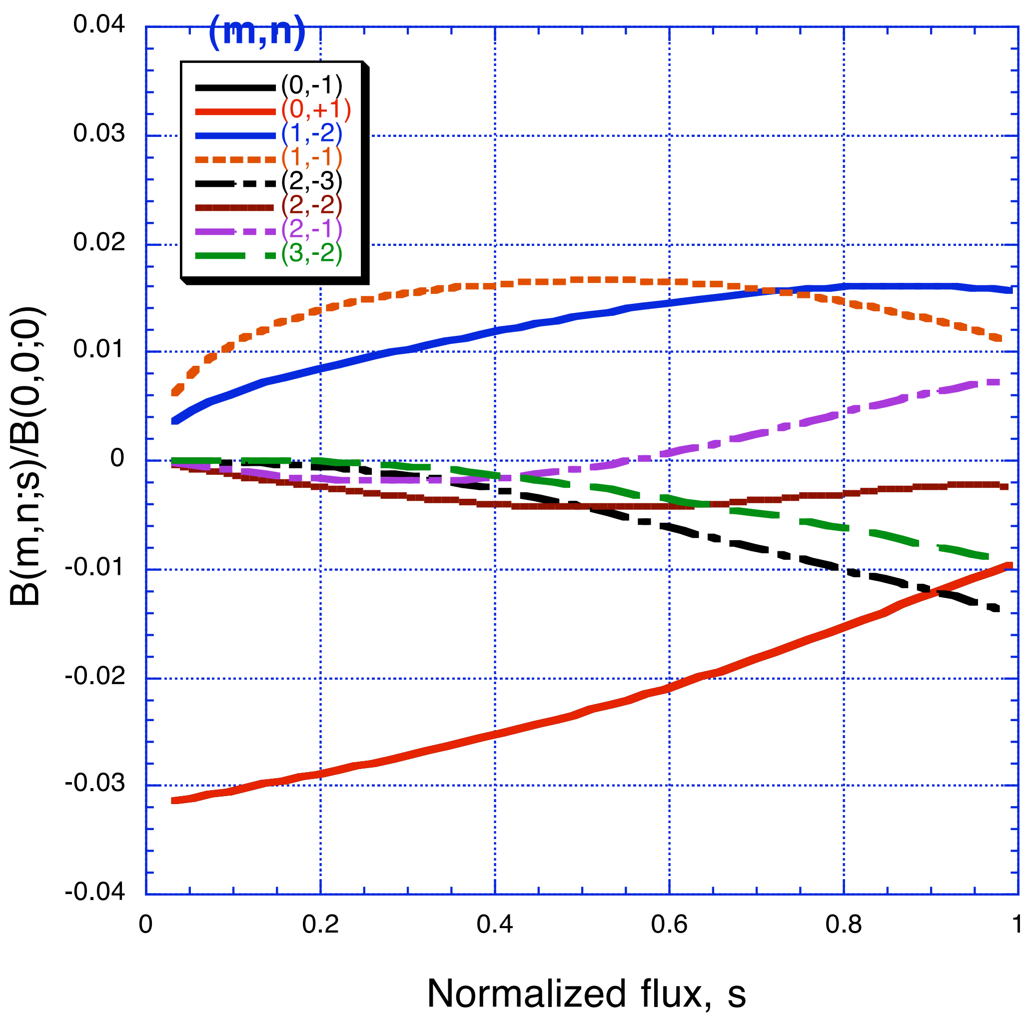
- Peak heat load appears to decrease with increasing number of particles and size of segment.
- Peak heat load ~ 15 MW / m^2; Average heat load ~ 2.4 MW/m^2

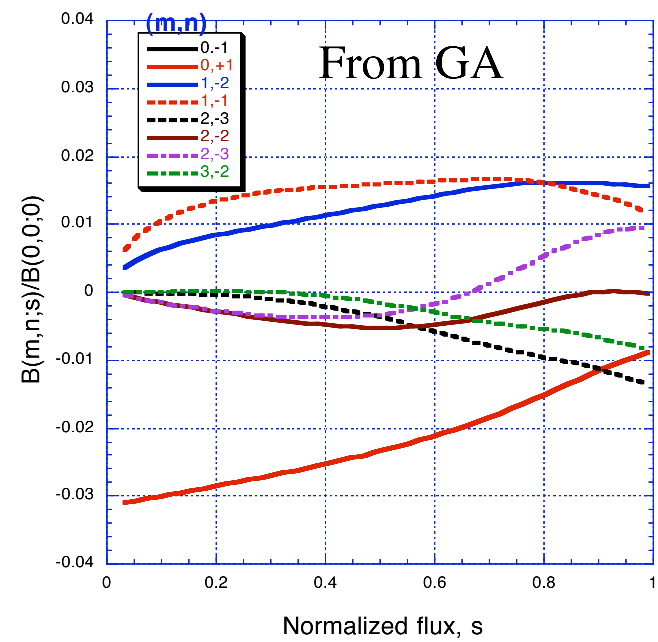




Non-Axisymmetric Magnetic Field Residuals

- n≠0 field residuals can cause enhanced losses. We re-ran ORBIT3D with the (0, +1) component removed; Did not observe reduced loss. Other components will be tried.





Status of Coil Optimization for MHH2 CS

- Objective is to perform analysis in the detailed design and optimization of magnetic coils and plasma-facing components
  - more efficient interaction with UCSD engineering group

- We obtained two coil design codes and are learning to run them :

  - NESCOIL: An interface was created to provide input to Cad drawing of the coil set for the MHH2 configuration

  - COILOPT: To examine the coil set for MHH2 16-coil case, we need:
    (1) VMEC equilibrium with reasonable bootstrap current profile
    - VMEC equilibrium (w/o net current) obtained at PPPL & GA
    (2) Representation of the filaments (from NESCOIL) in winding law expansion of (u,v) on the winding surface. This is now on-going.

- We will consider some capability of running fixed boundary VMEC.

Summary & Future Work

- A preliminary assessment of □ particle losses has been performed for the MHH2 16-coil CS configuration. The □ energy loss fraction is found to be 34% with most energy lost just below the OB mid-plane.

- Under some simplifying assumptions, the peak □ heat load on the LCMS is ~ 15 MW/m^2 for the R=7.5m and □=4% 16-coil configuration.

- **In the future**, we will like to

  - Obtain VMEC equilibrium with some reasonable BS current profile for the 16-coil and 12-coil cases, and re-examine the □ loss issue in more detail.
    Perform inversion from Boozer to real coordinates in assessing heat load distribution.

  - Continue performing examination of MMH2 16-coil and 12-coil sets using NESCOIL and/or COILOPT.