Status of Alpha Loss and Heat Load Assessments for 2 Field-Period CS

T.K. Mau
UC-San Diego

ARIES-CS Project Meeting
June 16-17, 2004

University of Wisconsin, Madison

Some Background Information

- Alpha particle confinement is a topic of interest in the ARIES-CS project:
  - *It is an issue unique to fusion reactors;*
  - *Localized and/or excessive alpha energy loss can make divertor design very challenging;*
  - *Energy particles hitting PFC's can lead to blistering of surface materials.*

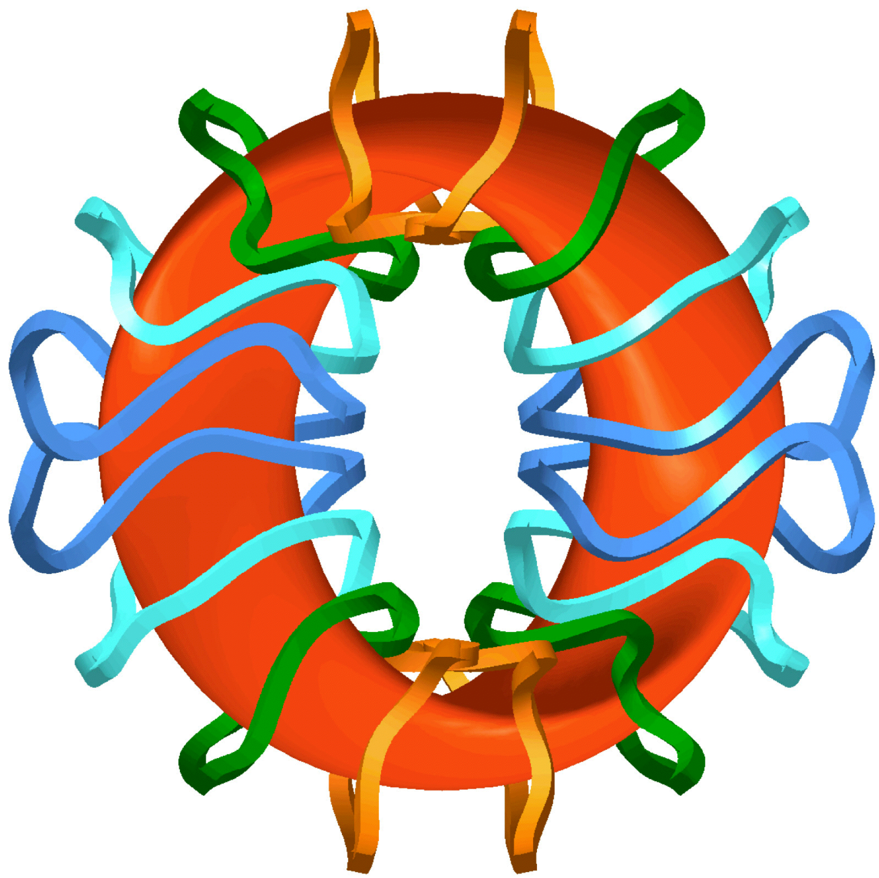
- Several visions of a CS configuration are being considered for exploratory studies, including 2 and 3 field periods, and 18, 16, 12 and 8 modular coils.

- In the March 04 meeting, a preliminary study of □ particle loss in an MHH2 configuration (with 2 field periods and 16 coils) was presented.
  - ~35% of □ power is lost.
  - *The lost □ footprint at LCMS exhibits a pattern in (□,□) space that is different from previous results observed in the NCSX-based configuration.*
  - *Under simplifying conditions, the peak heat load for a typical 2GW fusion power reactor is ~15 MW/m^2 -- a challenge for and divertor and PFC designers.*

- In this presentation, I will try to address some of these issues, and comment on what physics tasks need to be done in the area of PFC design.

Parameters for the MHH2 16-coil CS Candidate

Number of field periods	2
Number of coils	16
□$_{c-p}$ (m)	1.38
□$_{c-c}$ (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
□ (%)	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

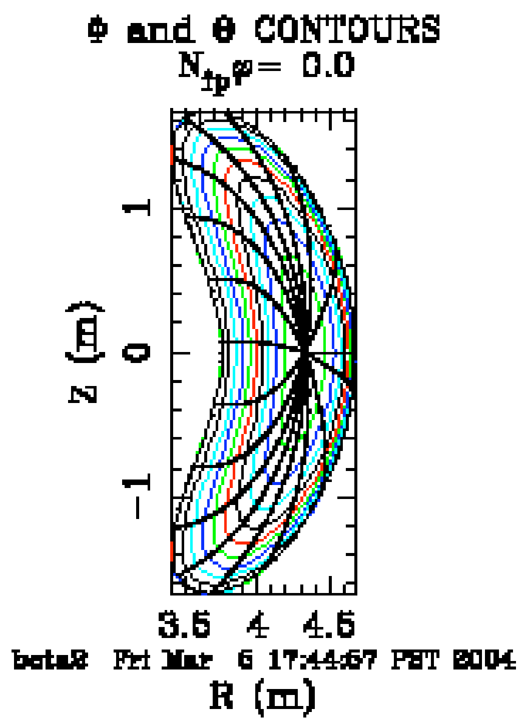
Finite-β CS Equilibrium and Assumed Plasma Parameters

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

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

  $\beta = 4.52\%$

  There is little net toroidal current in the plasma.

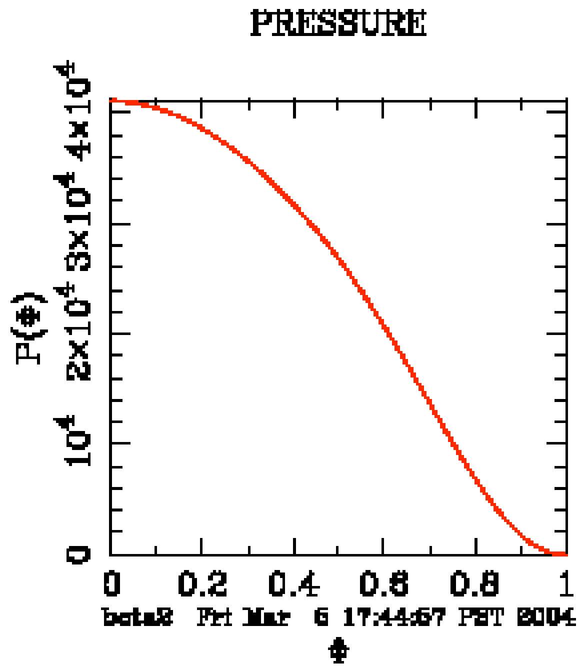


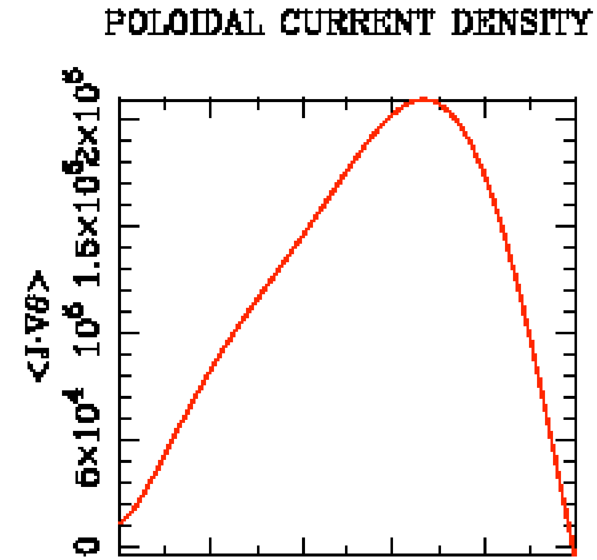
- It assumes $B_o = 5.5$ T, $R = 7.5$ m, and
  $n_e = n_i = 1.3 \times 10^{14} \, (1 - s^2)$ cm^{-3}
  $T_e = T_i = 11.5 \, (1 - s^2)$ keV

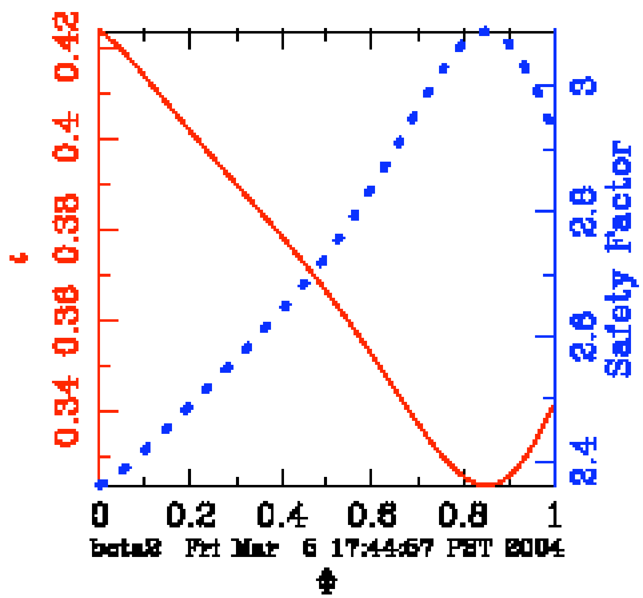
  Initial $n_\alpha \sim (1 - s)^8$

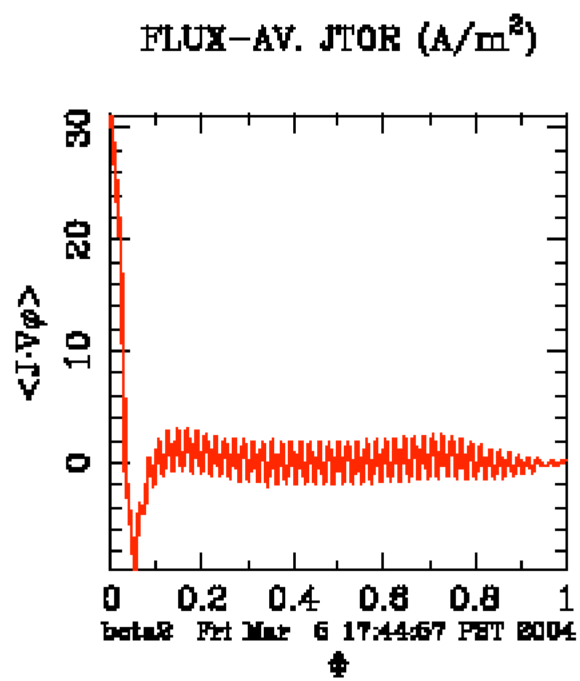
- The sample size used is 4000 particles.
  Particles are collisionless; energy drag and pitch angle scattering on the background plasma.
  Particles are followed for 1-2 slowing-down times (~0.2 s)

Detailed Profiles of 4.52%β, MHH2 Equilibrium (L. Lao)





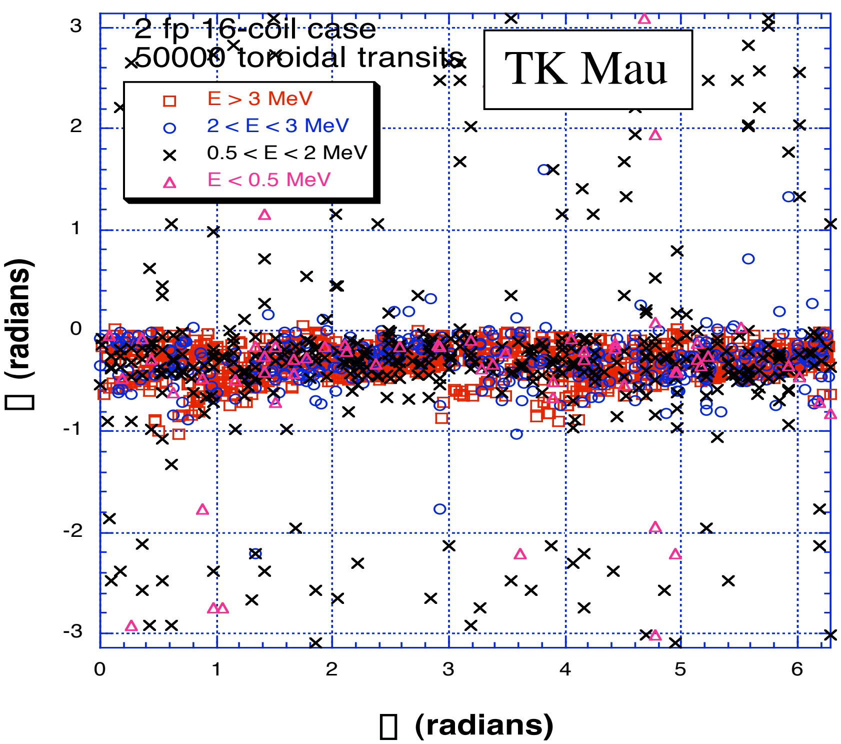


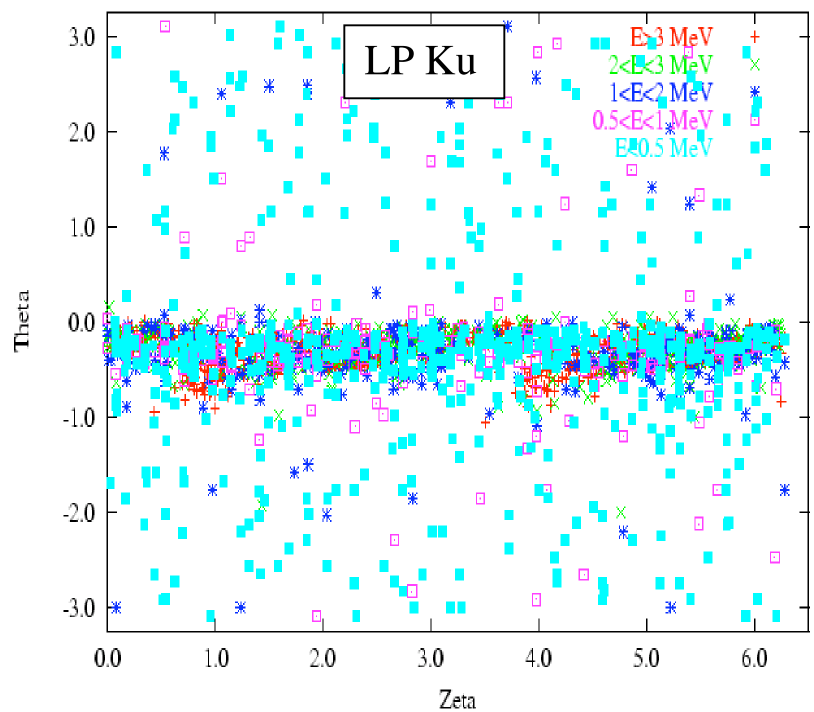


Implications for Agreement between Two ORBIT3D Runs

- In both runs, particles are lost uniformly along the toroidal direction, with a weakly discernable periodic structure of the footprint. Runs on NCSX-based cases indicated clear band-like toroidal structures. MHH2 appears to exhibit larger energy loss fractions than NCSX-like cases (?).
- Could this be due to the lower aspect ratio (=3.75) in MHH2 as compared to A=4.5 in NCSX? Lower A leads to larger initially trapped particle fraction leading to larger prompt loss.

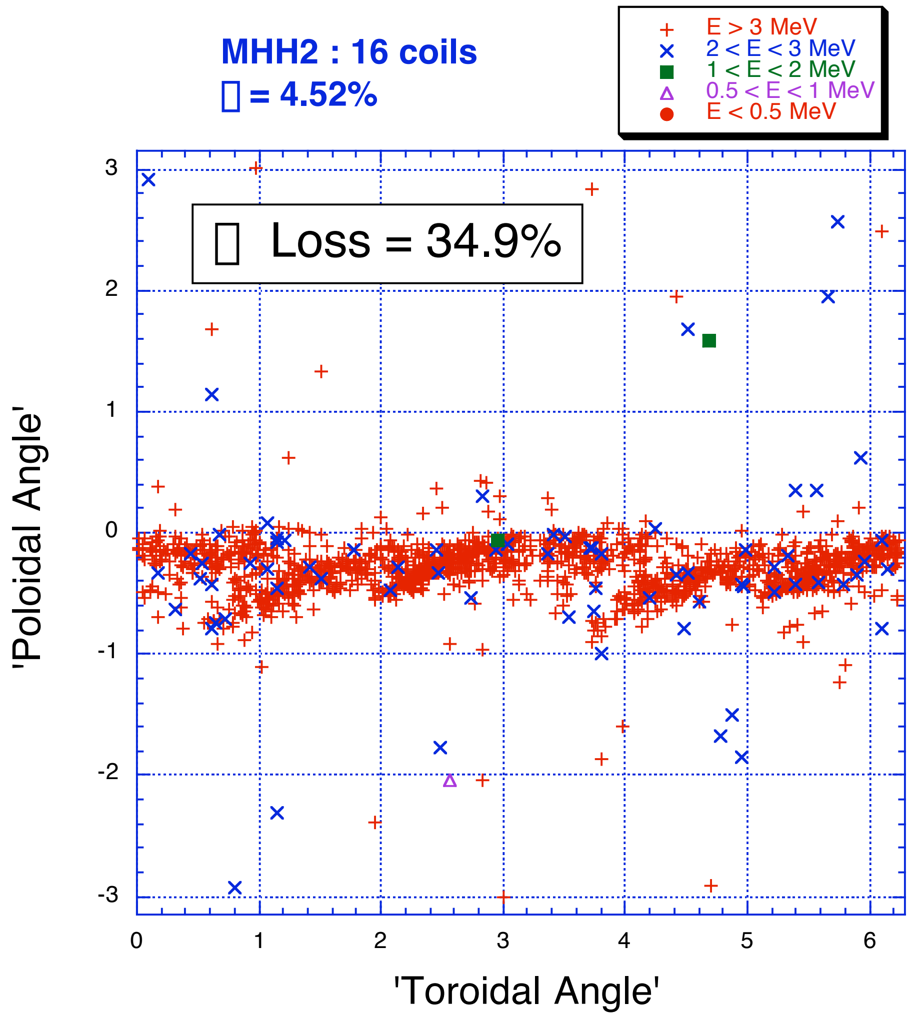
MHH2 optimization w.r.t. □ loss fraction should be considered.

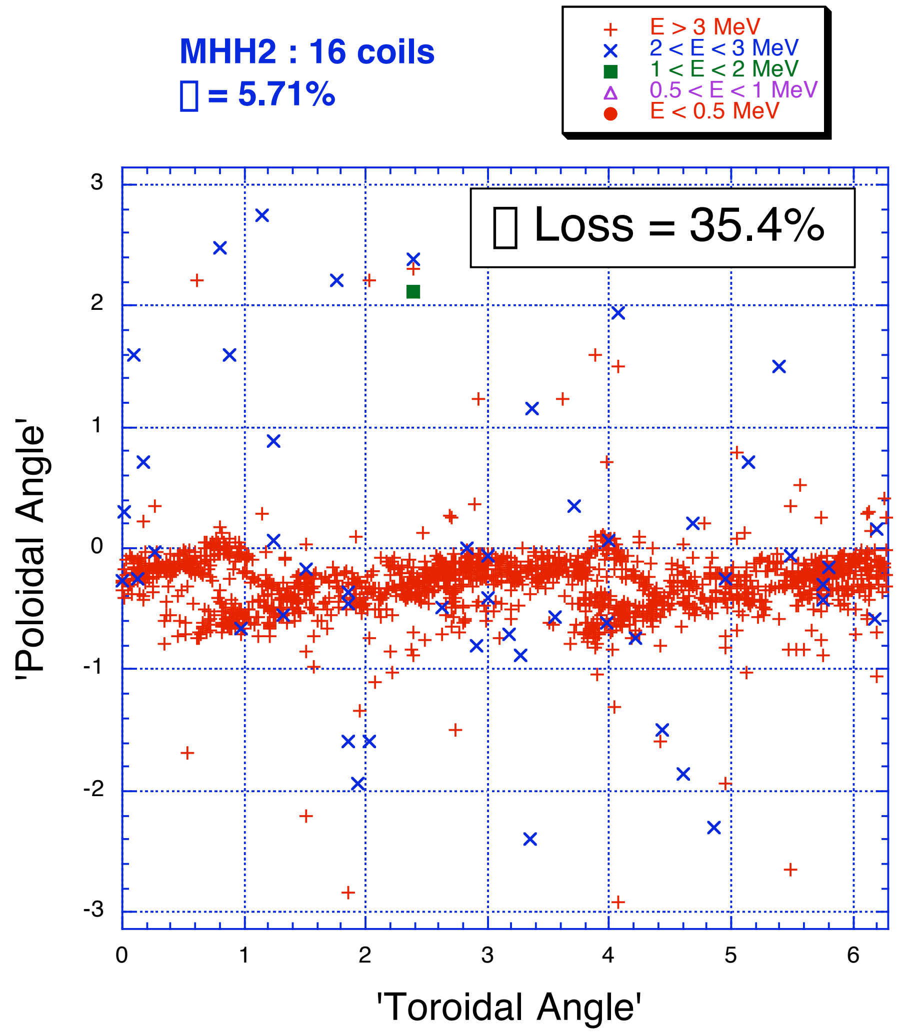




Comparison between Two MHH2 Cases with Different Beta Values

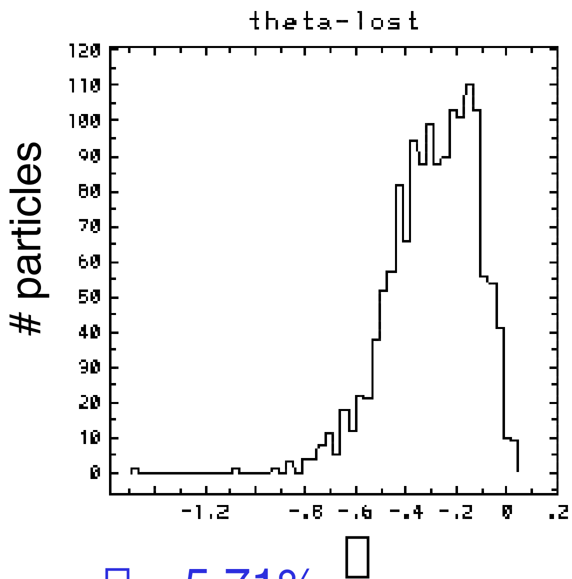
- The lost footprints at LCMS for the two cases are quite similar; so are their energy loss fractions. The global characteristics appear to be insensitive to plasma .

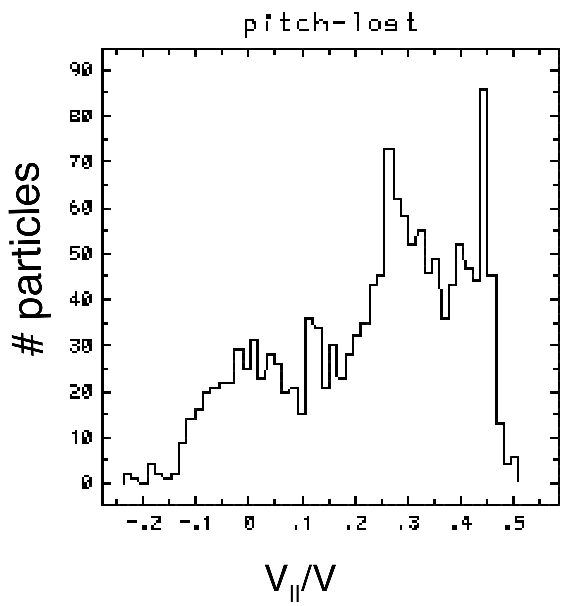


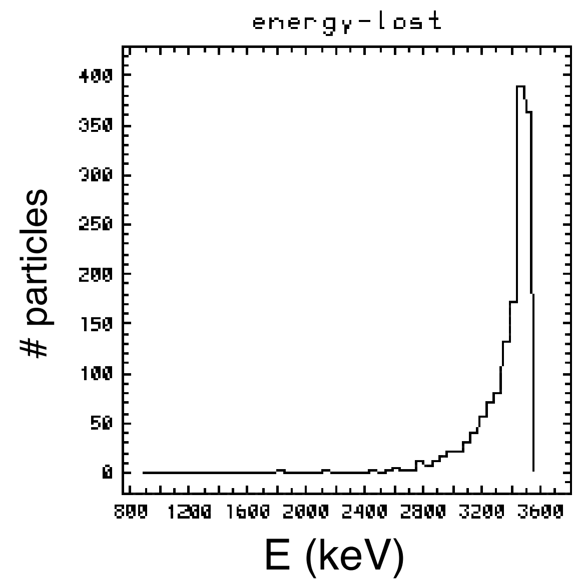


Details of Alpha Loss Characteristics Appear to Depend on □

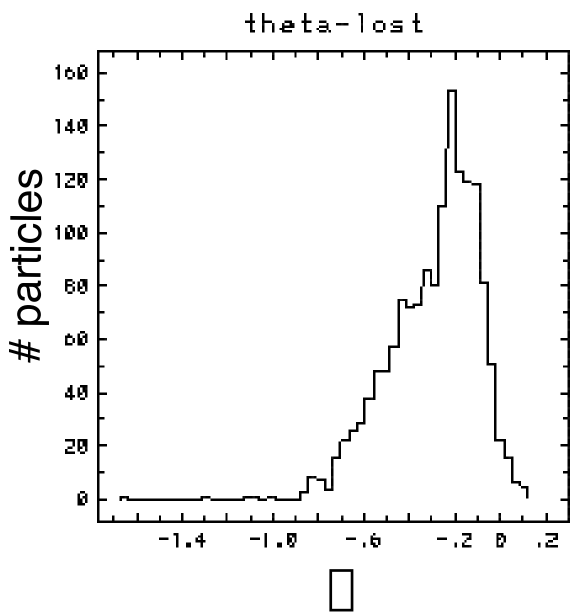
□ = 4.52%

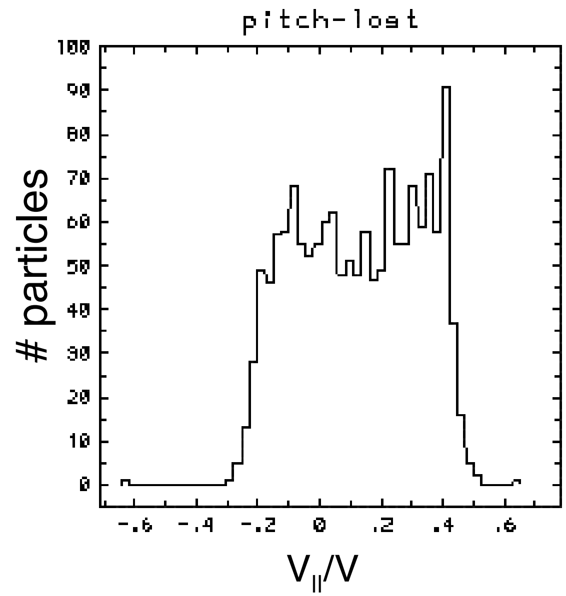


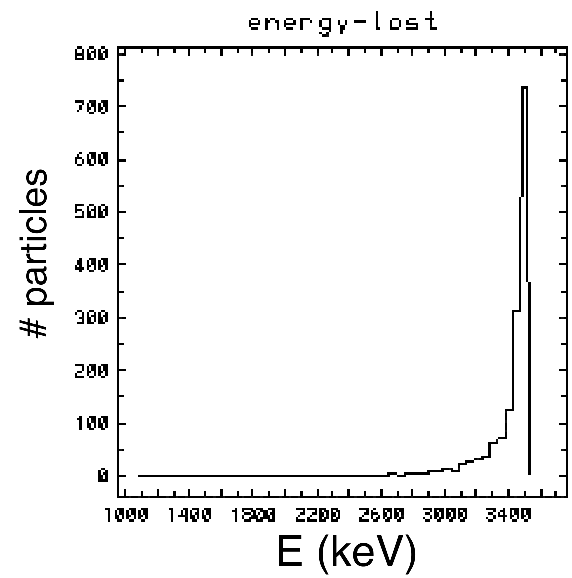




□ = 5.71%







Revised Estimate of Heat Load on LCMS due to Lost Alphas

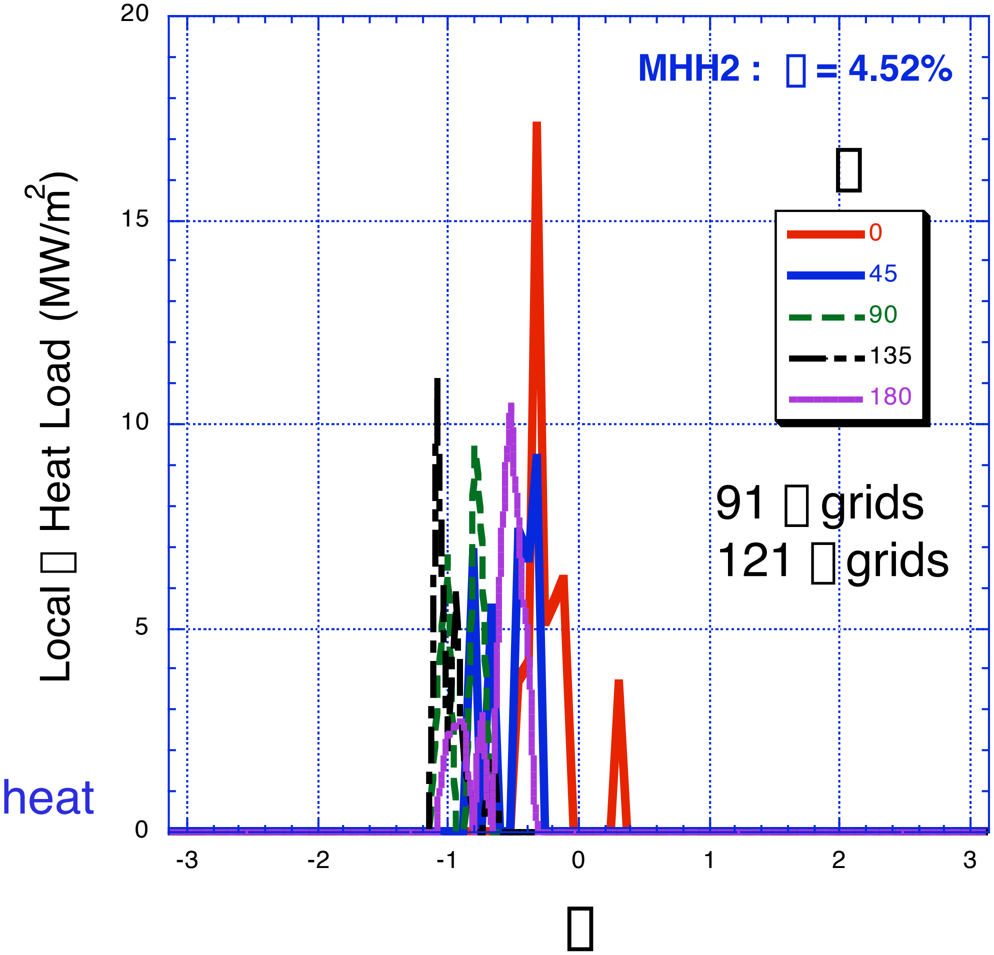
- Heat Flux on LCMS is estimated by dividing the plasma surface into rectangular segments, and adding up the energy collected in each segment. For P_{fus} ~ 2000 MW, $P_{□}$ ~ 400 MW, and total power to surface is $f_{□L}$ $P_{□}$ where $f_{□L}$ is fraction of a energy lost.
  Heat load to segment: $W_{□} = f_{aL}\, P_{□}$ □ (□E/E_{tot})/Area

- For each grid point (□,□) on LCMS, the corresponding Boozer coordinate □*(□,□) is calculated using

$$□^{*} = \sum_{m,n} □_{mn}(s=1)\sin(m□ □ n□)$$

  to ensure each lost particle is accounted for in the right segment.

- A rough sampling of the heat distribution indicates the peak heat load to be ~ 15 MW/m².



Approach to Addressing Alpha Heat Load Issues in Stellarators

- For the ARIES project, the only approach is to make use of modeling tools based on the most up-to-date physics models and computational hardware to compute the heat load on intercepting plates located in the SOL and the first wall.

- First, the alpha particle confinement (loss from the plasma) must be accurately modeled. Existing guiding-center orbit codes (ORBIT3D, PGCC) can be used with a sufficiently large sample of particle, in order to determine the exit location and energy of each lost particle.

- Second, knowing the initial location and energy of each exited particle, one can follow its guiding-center trajectory by tracing the appropriate field line outside the LCMS (GOURDON code) on an accurately computed SOL magnetic field topology including plasma and current effects (VMEC/MFBE).

- Third, an algorithm specifying the geometry and location of the various intercepting divertor plates and baffles, and the first wall, and keeping track of groups of particles hitting these obstacles needs to be devised (GEOM). This can become a powerful tool to design the location and shape of the various components.

Results of a GEOM/Gourdon Run for W-7X

- This is a case of injecting 65 keV D neutral beams in W-7X, with resultant lost beam ions hitting divertor plates, baffles, and side plates (so no particles hit VV wall).
- In the ARIES project, we have capabilities in ORBIT3D, VMEC/MFBE, and GOURDON.
- The GEOM code is the missing element, which we are in the process of acquiring (Grossman).

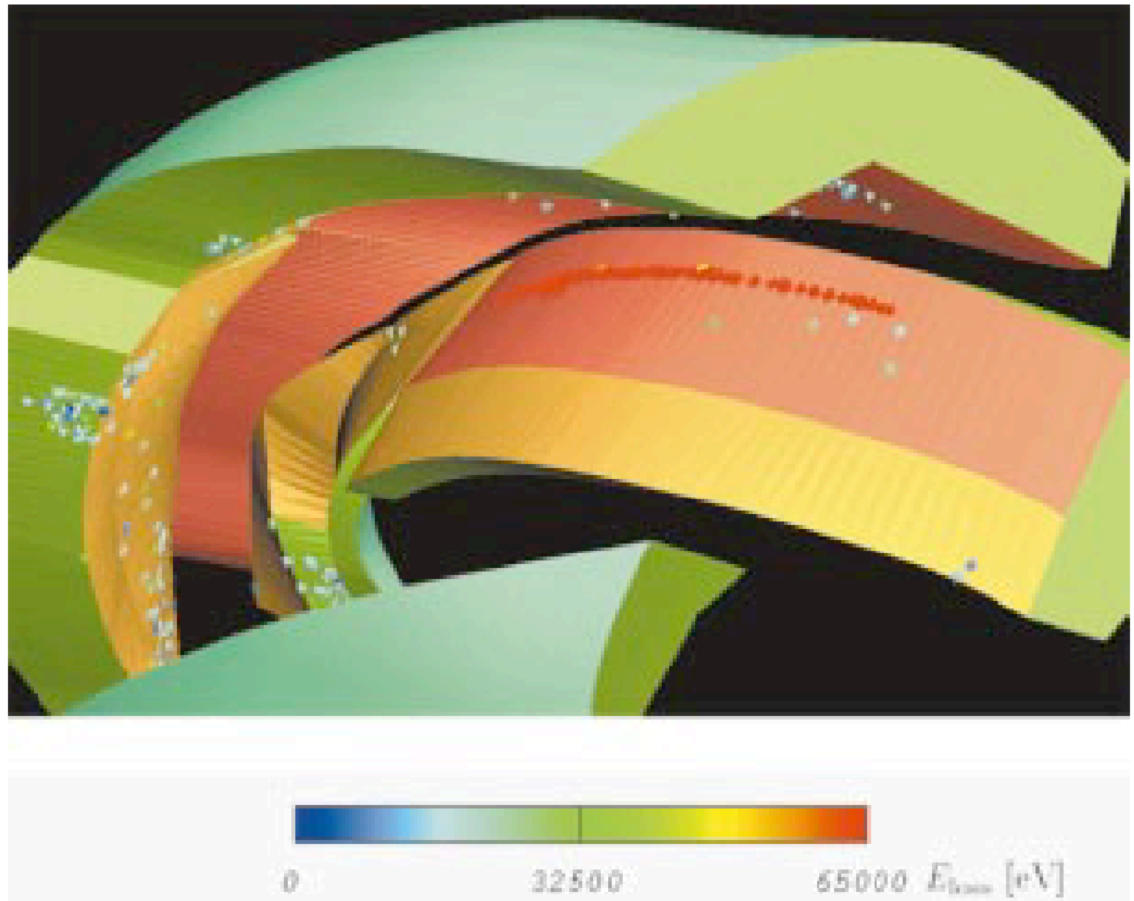


Figure 14. Particle deposition on an upper target plate system (divertor plates (pink), baffle plates (orange) and side plates (green)) for lost counter-injected deuterons. The particle intersection points are characterized by the particle energies.

Strumberger, *Nuclear Fusion* 40 (2000) 1713.

A List of Related Issues

- Alpha particle core confinement:
  - An algorithm of converting the Boozer coordinates of lost particles to real coordinates needs to be developed.
  - Can ~3 MeV alpha particle gyro-motion be neglected, particularly when crossing the LCMS into the SOL?

- Alpha particle orbit in SOL:
  - Another approach using the code set PIES + Drevlak + Field-line Integrator (that accounts for magnetic islands) has been suggested. Will the ARIES project be able to take advantage of it?
  - Given that a ~3MeV particle has gyro-radius of the order of SOL width, is the guiding center orbit still adequate in describing the interception of these particles by the plates?

- Deposition of alpha particles on target plates:
  - Can one avoid energetic alphas hitting the first wall via stochastic behavior of field lines?
  - Will the spectrum of alphas impinging on the plates cause blistering of surface materials?

Can a divertor system be optimized for both thermal and alpha heat loads?

Summary & Future Work

- Assessment of α particle losses has been performed for the MHH2 16-coil CS configurations with finite β, prepared by GA. The α energy loss fraction is found to be ~35% with most energy lost just below the OB mid-plane for both β=4.52% and 5.71%; however the energy and pitch pitch distributions of the lost particles are different.

- A preliminary revised analysis gives the peak α heat load on the LCMS of ~ 15 MW/m^2 for an R=7.5m and β=4.52% MHH2 configuration.

- Optimization of MHH2 configurations w.r.t. alpha confinement by identifying the main non-axisymmetric field component that causes the loss.

- An algorithm for converting from Boozer coordinates to real coordinates is being developed.