NERSC REQUIREMENTS WORKSHOP: FES

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and the RF SciDAC Team

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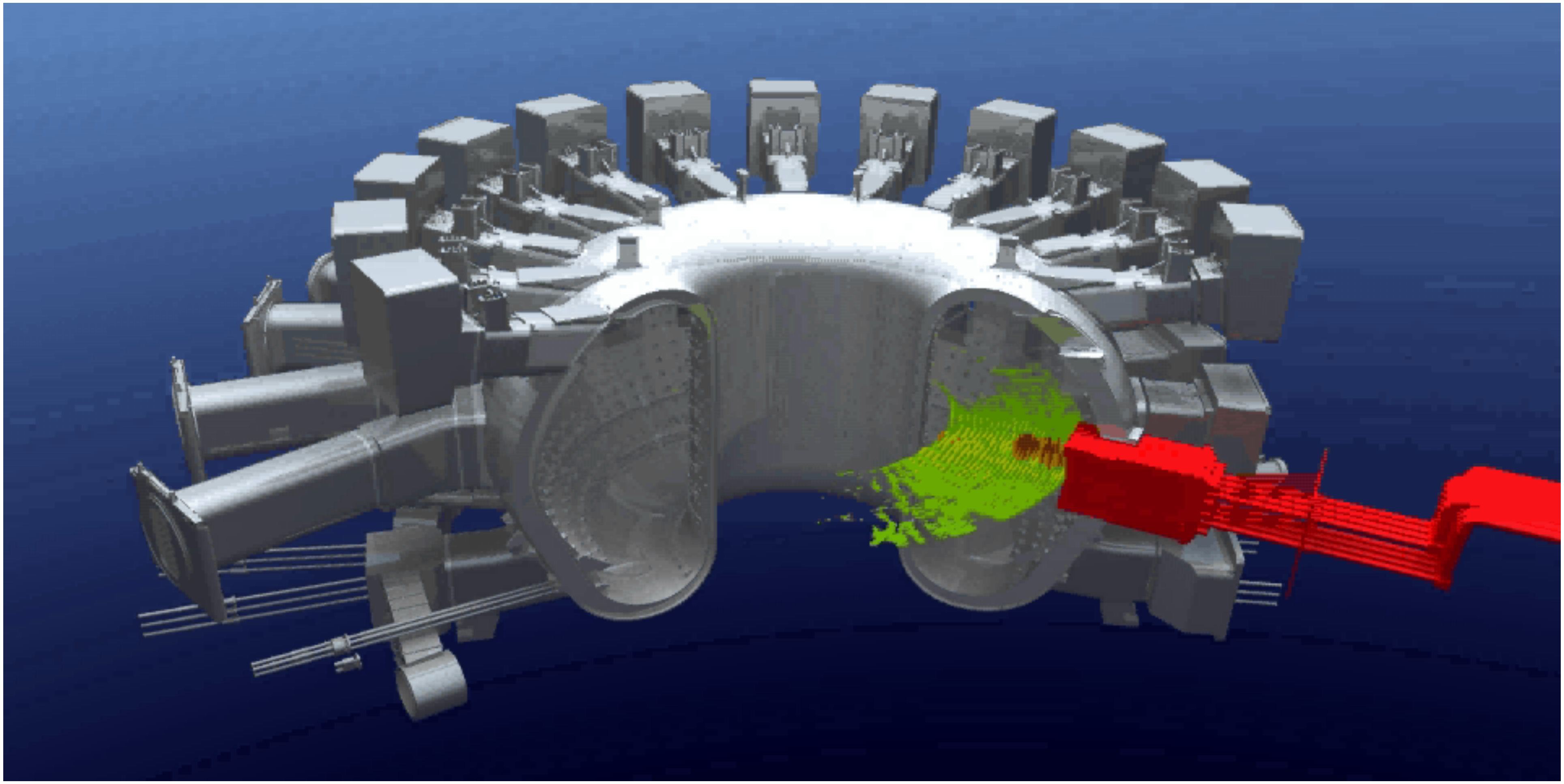
High Power RF in the Ion Cyclotron Frequency Range (ICRF) Is Used to Heat, Drive Current, Affect Plasma Stability

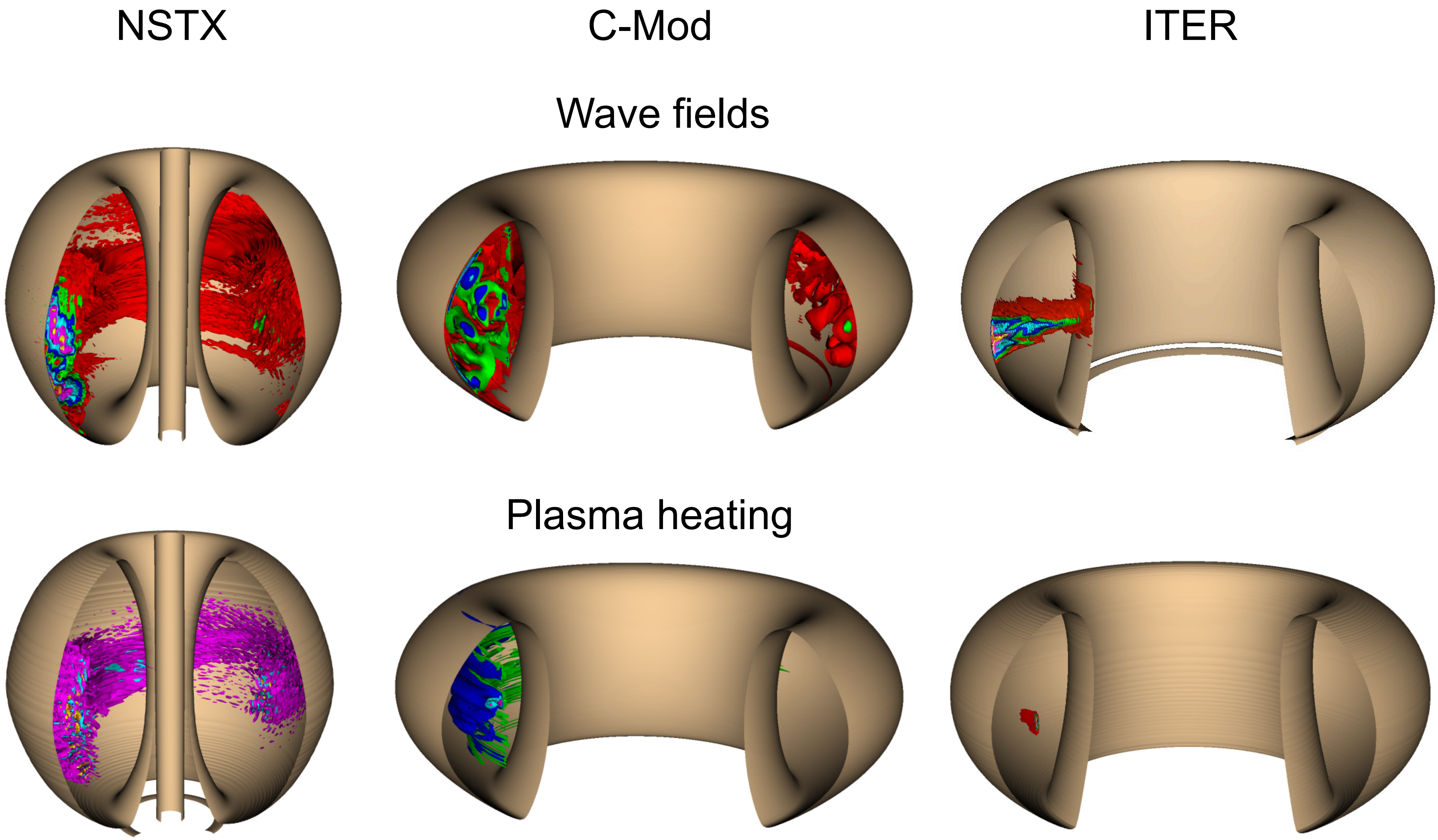
Lower Hybrid Current Drive (LHCD) Is Used to Drive Current



RF SciDAC Scientific Objectives
Increase Our Understanding of:

- **Parasitic losses in the boundary plasma between the RF antenna and the core plasma => make RF routine;**
- **RF interactions with energetic electrons and ions in the core to quantify how these species affect power flow in the confined plasma => optimize plasma performance;**
- **RF effects on fast-particle driven instabilities to explore how these interactions increase (decrease) the instability drive => avoid reduced fusion power.**

Three-D Simulations Are Needed to Understand Device-Dependent Wave-Heating Physics



Formulation of the Wave Propagation and Absorption Problem

For time harmonic (rapidly oscillating) wave fields **E** with frequency ω, Maxwell's equations reduce to the Helmholtz wave equation:

$$-\nabla\times\nabla\times\mathbf{E}+\frac{\omega^2}{c^2}\left(\mathbf{E}+\frac{i}{\omega\varepsilon_0}\mathbf{J}_p\right)=-i\omega\mu_0\mathbf{J}_{ant}$$

The plasma current ($\mathbf{J}_p$) is a non-local, integral operator (and non-linear) on the rf electric field and conductivity kernel:

$$\mathbf{J}_p(\mathbf{r},t)=\sum_s\int d\mathbf{r}'\int_{-\infty}^{t}dt'\sigma\left(f_{0,s}(E),\mathbf{r},\mathbf{r}',t,t'\right)\cdot\mathbf{E}(\mathbf{r}',t')$$

Wave Solvers (AORSA) (TORIC)

SIGMAD

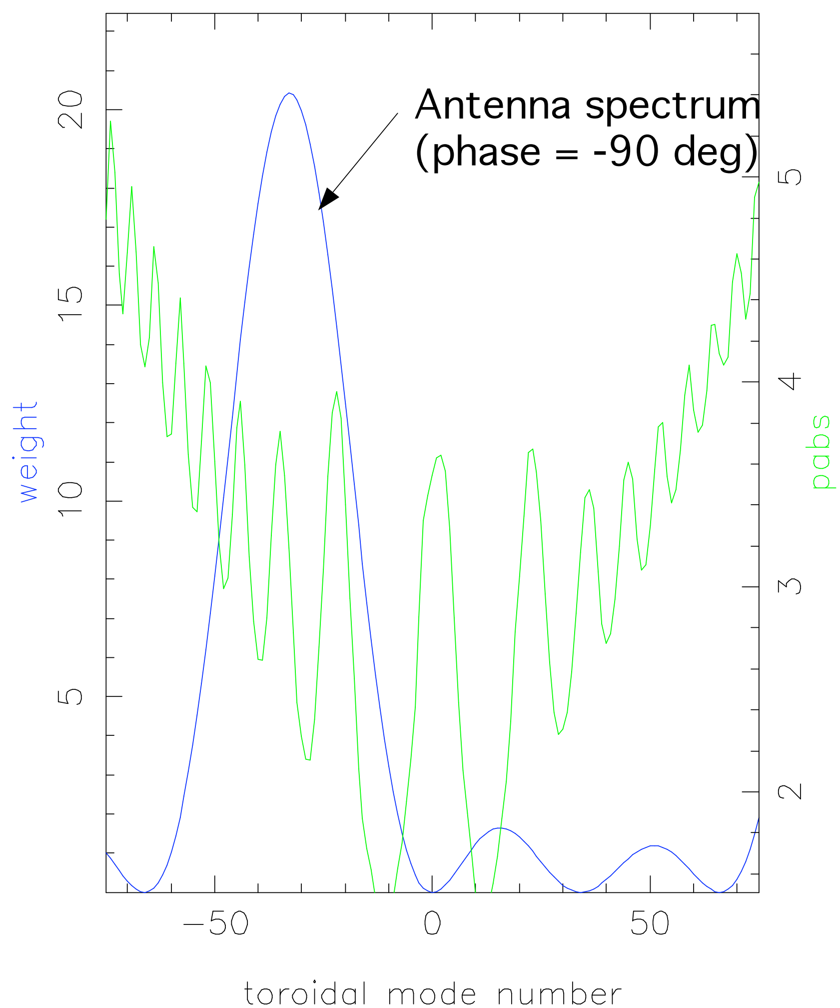
The long(er) time scale response of the plasma distribution function is obtained from solutions to Fokker-Planck equation or (five year objective) Alfvén-regime simulations

Plasma Response (CQL3D-DC) (ORBIT-RF)

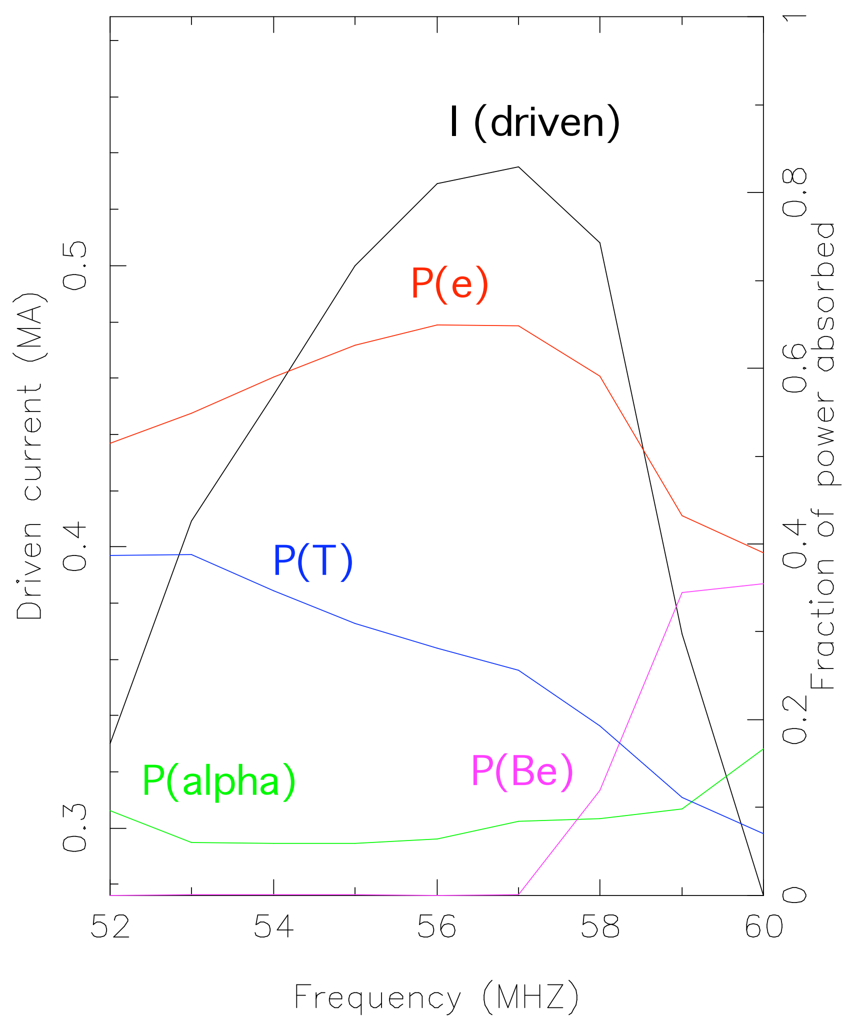
MPI is the dominant parallelization technology

Current Drive Sensitivity Studies Show Maximum at ~57 MHz

Toroidal spectrum at 58 MHz

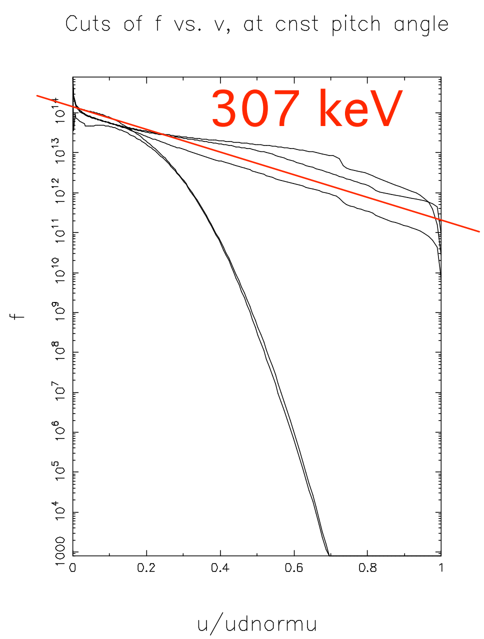


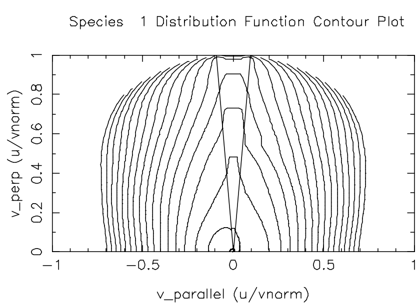
ITER Scenario 4



ICRF Can Drive (Enhance) Energetic Particle Populations from Minorities, NBI, or Fusion Alphas

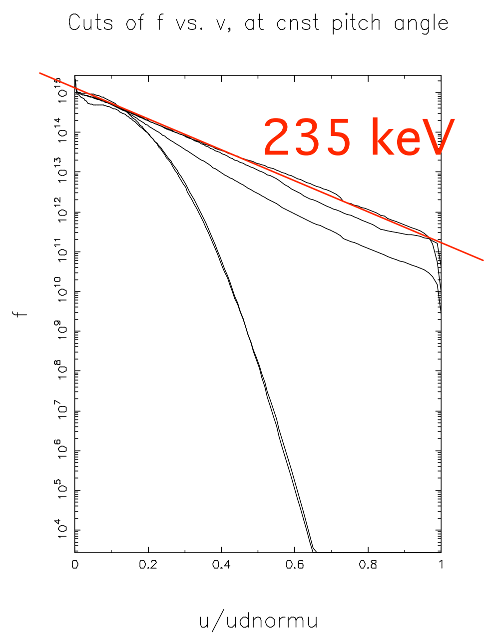
10 % D

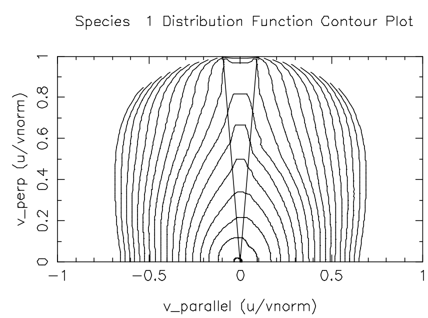




P(D) = 13.9 MW
(66.3 %)

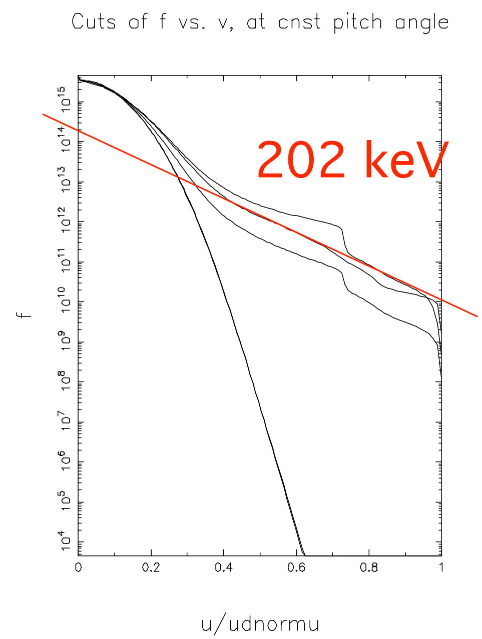
30% D

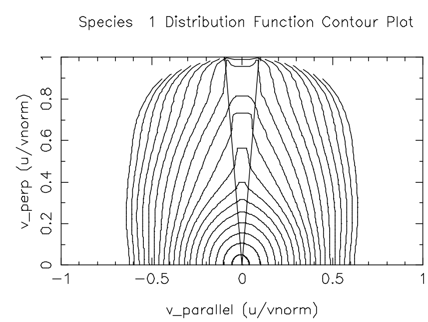




P(D) = 12.9 MW
(61.2 %)

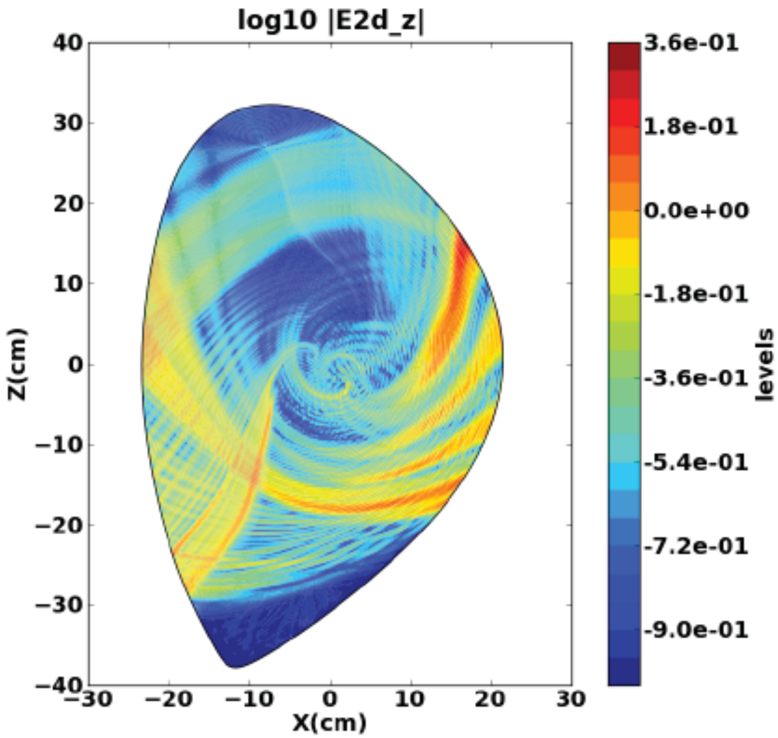
50% D

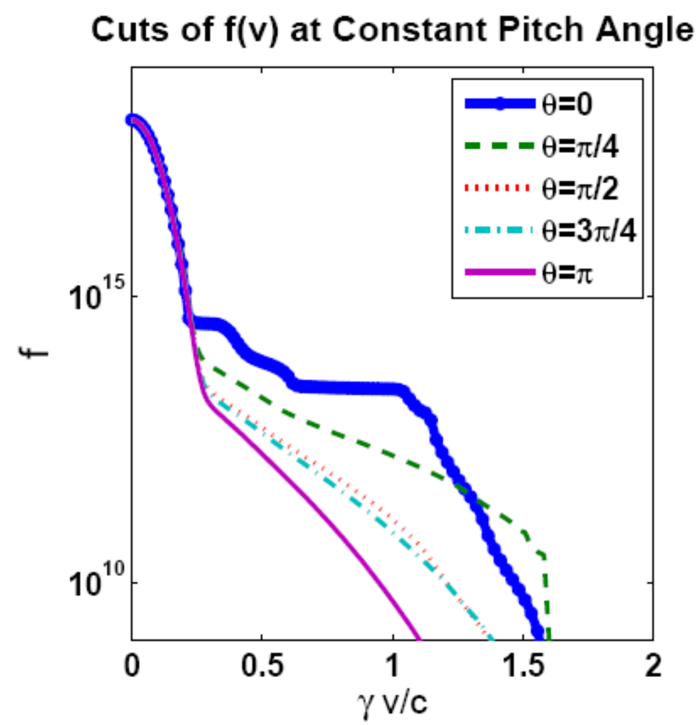




P(D) = 8.5 MW
(35.7 %)

Combined full-wave spectral solver and electron Fokker Planck code has been developed – TORIC LH & CQL3D [Wright, PoP, 2009]:





LH wave fields and electron distribution after 4 iterations between TORIC-LH and CQL3D for weak damping in Alcator C-Mod

[$n_{//}$ = 1.55, $T_e(0)$ = 2.33 keV, f_0=4.6 GHz, N_R = 980, N_m = 1023]

Usage Characterization Characterization:

- Run (3D) is typical for one set of plasma conditions, medium to low resolution, no particle coupling, no time-dependent evolution
  - Processors: 5000 (x5)
  - Hours: 5 (x2)
  - Memory: 1 GB/core (x2)
  - Data: relatively small, no restart
- Annual use:
  - ~ 3 M processor-hours, equally split between NERSC and NCCS

RF SciDAC Scientific Objectives Based on Increased HPC Resources:

- Coupled core-to-edge simulations that lead to an increased understanding of parasitic losses in the boundary plasma between the RF antenna and the core plasma
- Simulations of core interactions of RF power with energetic electrons and ions to understand how these species affect power flow in the confined plasma.
- RF effects on fast-particle driven instabilities to understand if these interactions increase (decrease) the instability drive that can lead to reduced fusion power.

Computational/Physics Characteristics of Five-Year Goals

- Three-D will become routine, many runs will evolve time and/or iterate. Particle-based RF will start becoming feasible.
- High-resolution edge that resolve antenna features are planned.
- Edge is non-linear (parametric decay, sheaths, stochastic interactions) and must be coupled to core.
- Coupling (loose to start) with kinetic Alfvén-regime simulations.
- Run characteristics:
  - Cores: 2 M (5x)
  - Memory: 1 GB
  - Time: 4 hr (x3)
  - Data per run: 1.2 TB (restart)
  - Files: 600 GB (restart)

GPU/CPU Strategy

- Codes are good candidates for efficient use of GPU acceleration:
  - Compact compute-kernel routines
  - Dense/block linear matrix factors
  - Much of new physics based on coupling to particles
- Efficient libraries will be needed.
- Target architecture and programming models are evolving.
- General strategy is to start separating inter-node communication (MPI) from intra-node communication.

CUDA and AORSA

Current QL Operator –
•65~ length SIMD operation
•Accumulation over 2D worklist (200x200 to 500x500 points)

1. Worklist chopped up across 60 Cuda blocks, each executing 65 threads (3900 total threads)
2. Single block, 65 thread reduction follows at end

With almost no tuning:

	16xC1060s	**64x2.1Ghz Barcelona Processors (256 cores)**
Time (mins):	5	12

1500 lines of Fortran, C++, and Cuda replaced 500-600 lines of Fortran

DESIDERATA

- **Authentication—common GOV and/or DOE???**
- **Address role/needs of frameworks for multiphysics simulations**
  - **In-core lots of programming, difficult to debug**
  - **CPES => Kepler, SWIM => thin Python framework, FACETS => scripts plus wrappers/single executable.**
- **Tools, support for GPU development**
- **Benchmarks—CPU/GPU balance.**
- **Usable tools for portability: build and regression.**

Works Well, Could Work Better

- NX—switch Xclient-server with compression.
- Improved   Server Apps--better terminal etc.

Summary

- Physics opportunities are driven by need quantitatively predict how to heat, drive current, control stability for optimum reliability and performance, and design potential power-producing systems.
- Codes use present machines efficiently with dominantly strong (but occasionally weak) scaling.
- Future needs are driven by 3D, non-linear particle response, time-dependence.
- Use of GPU accelerated systems is likely, but will require tools, support and resources.