EBW Current Drive and Emission in Overdense Plasma

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NSTX Research Forum, Nov. 28-30, 2001

- EBW has accessibility to the plasma center in ST $\omega_{pe} >> \omega_{ce}$- plasmas.

- Strong cyclotron damping of these electrostatic waves holds the promise of localized, highly efficient CD.

- Conventional wave modes have difficulties with accessibility or too much/little damping. (For example, HHFW can strongly damp on beam ions.)

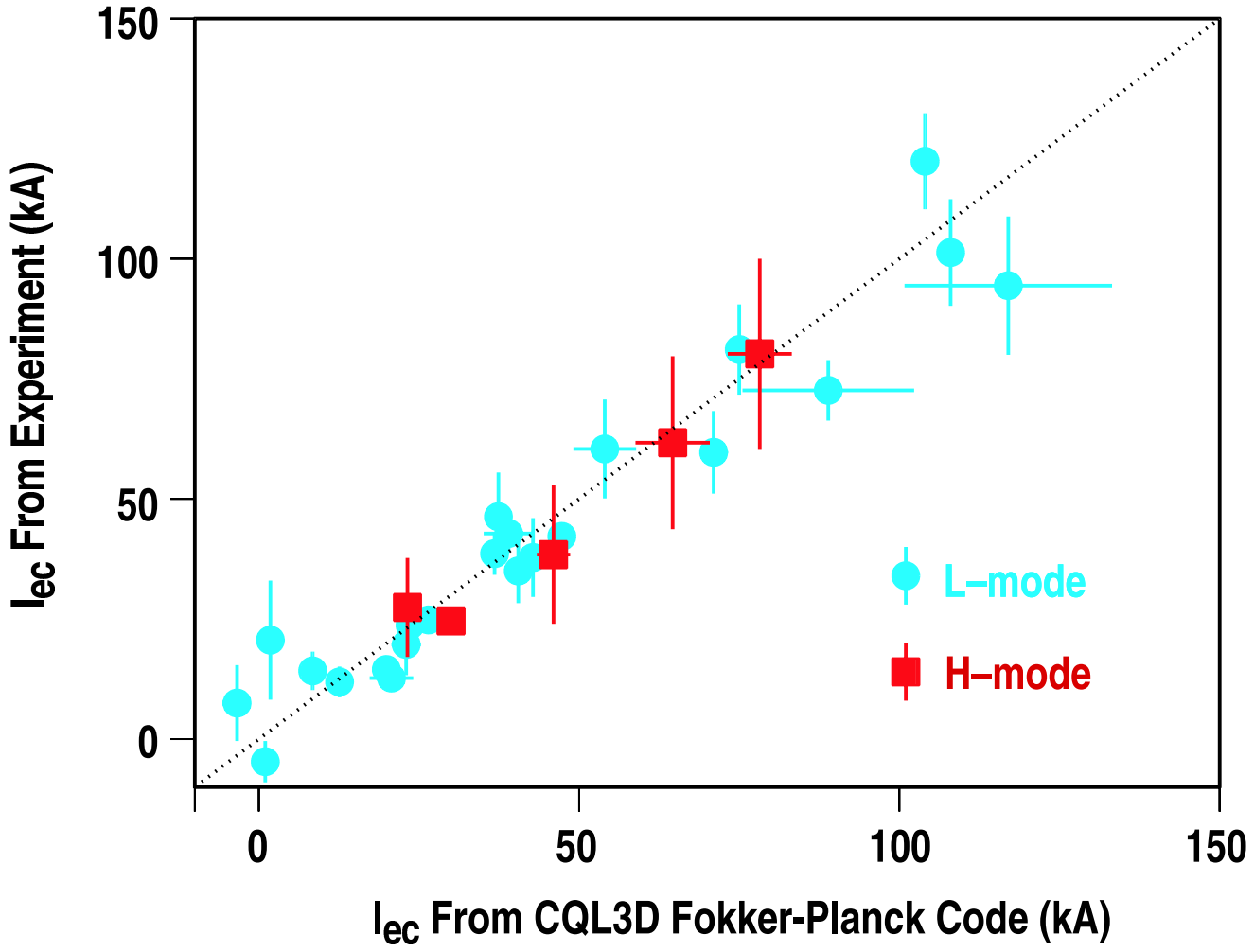
- Good coupling to plasmas is theoretically possible:
  - Ram et al., PoP **7**, 4084 (2000); Cairns et al, ibid., 4126.

- Emission experiments demonstrate up to 100% coupling:
  P.K. Chattopadhyay et al. and G.Taylor et al., 14th RF Pwr in Plasmas, Oxnard (2001).

- Ray tracing (GENRAY, Smirnov and Harvey) and CD calculations with the well benchmarked CQL3D Fokker- Planck code show efficient current drive:
  - Forest, Chattopadhay, Smirnov, PoP **7**, 1352 (2000)

- In following comparison of ECCD with DIII- D experiment (Petty et al., 14th RF, Oxnard), there are no free fitting parameters.

MEASURED ECCD FROM MSE DATA IS IN GOOD AGREEMENT WITH FOKKER-PLANCK CODE INCLUDING $E_{||}$ EFFECT



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GENRAY Ray Tracing Code

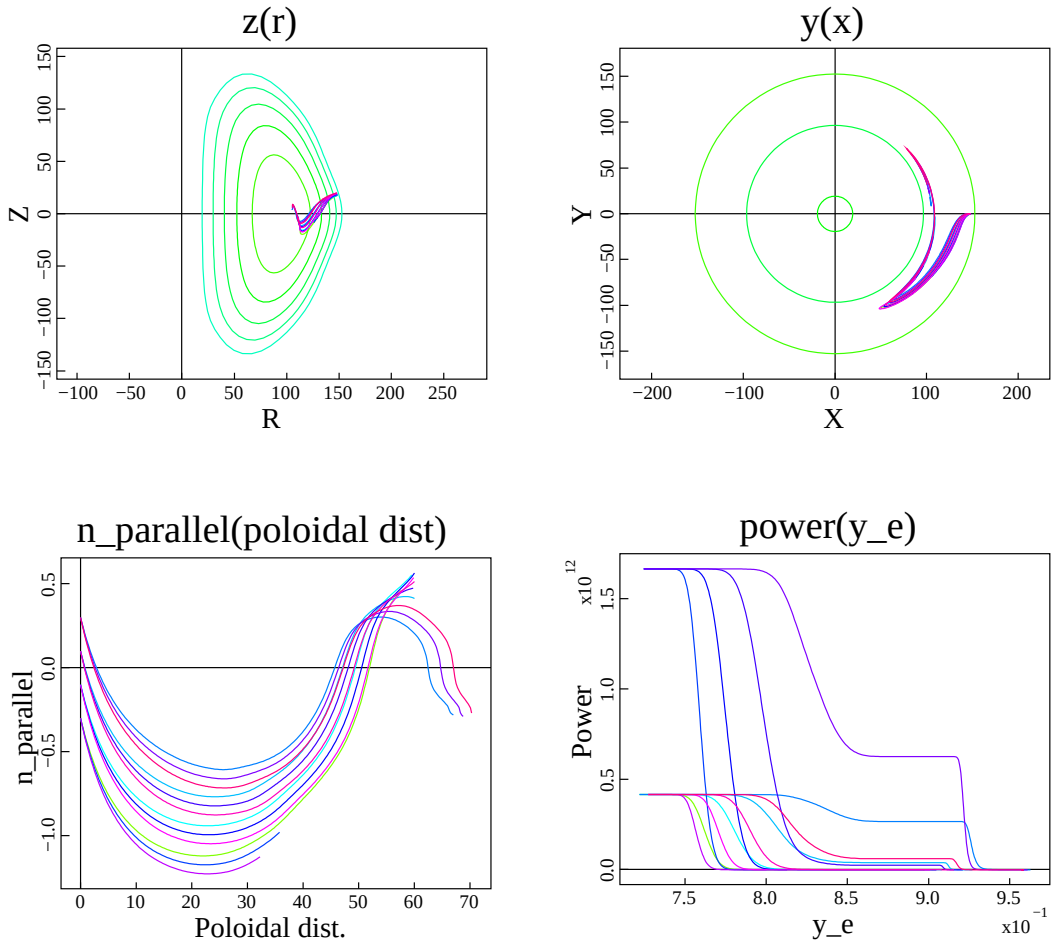
- General ray tracing code, applicable for all modes.
- Ray tracing is is 3D R,Phi,Z- coordinates, avoiding singularities at plasma edge and magnetic axis.
- Includes dispersion relations for relativistic plasma by Mazzucato/Fidone/ Granata, Shkarofsky, Forest full hot plasmaStix dispersion, and cold plasma.
- Numerical integration is Runge- Kutta, including numerical or analytic derivatives of the dispersion relation solutions.
- Has been applied to EBW, FW, LH, EC (O and X, 1st and 2nd harmonic) modes.
- Developed by Smirnov (primarily) and Harvey for previous 7 years.
- User manual available.
- **Following slides show application to EBW in NSTX,**

  for CD and emission/T_e studies.

Above Midplane Launch of EBW, with n_par=[−0.25,+0.25] over 10cm pol. length.

NSTX: n_e=6e13/cc, T_e=3 keV.

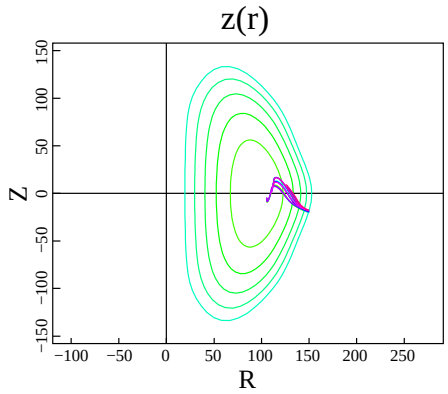
==> strong n_par downshift, penetration to cyclotron layer

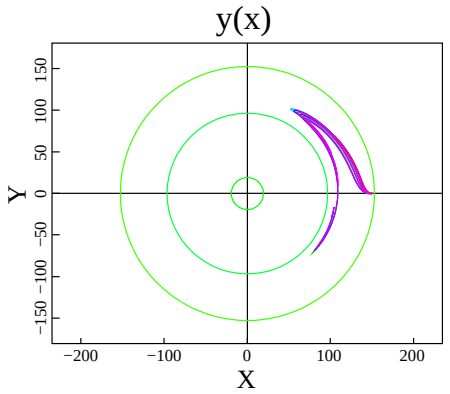


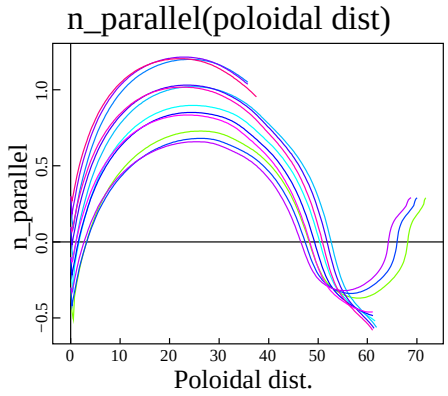
Below Midplane Launch of EBW, with n_par=[−0.25,+0.25] over 10cm pol. length.

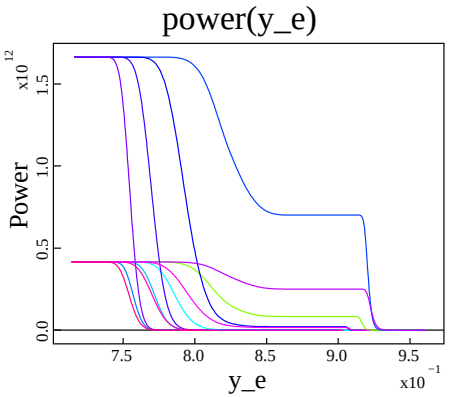
NSTX: n_e=6e13/cc, T_e=3 keV.

==> strong n_par upshift, penetration to cyclotron layer.







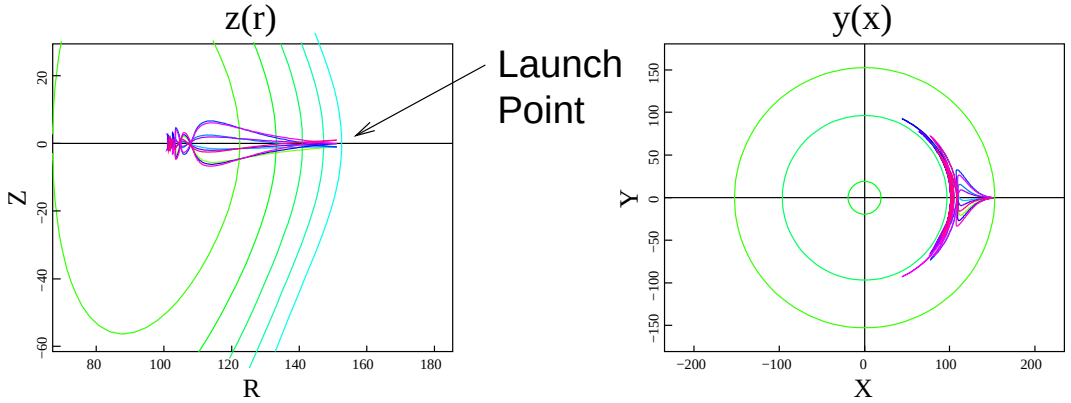


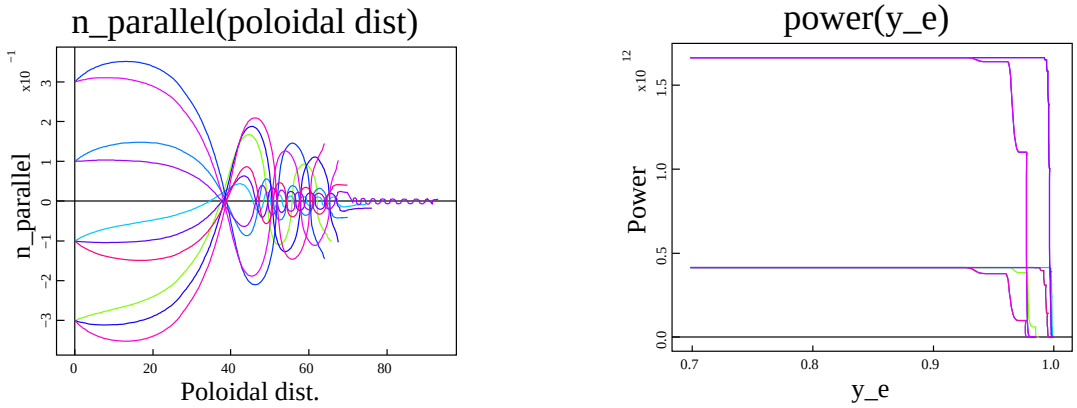
Midplane Launch of EBW, with n_par=[−0.25,+0.25] over 10cm pol length.

NSTX: n_e=6e13/cc, T_e=3 keV.

==> n_par is focussed to an absorption point near the cyclotron layer.

Some rays is this set (not shown) had n_par ==>0 and zero cyclotron damping (i.e., became perpendicularly propagating Bernstein modes).





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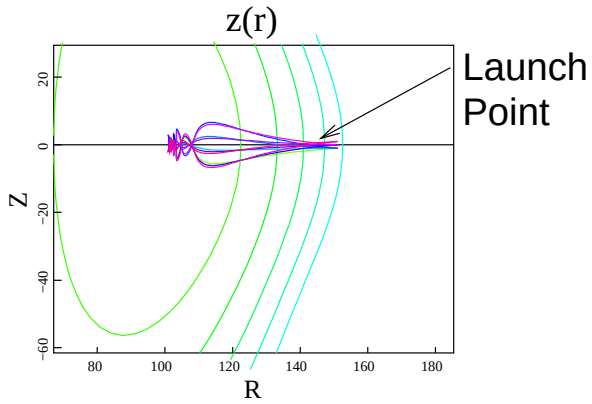
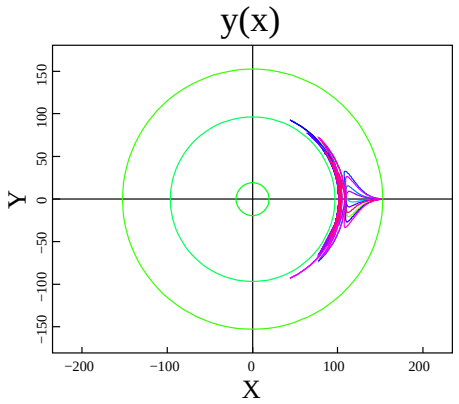
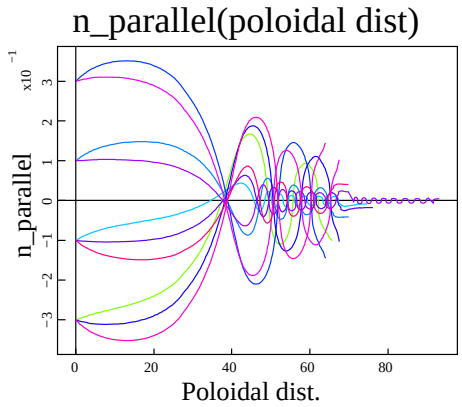
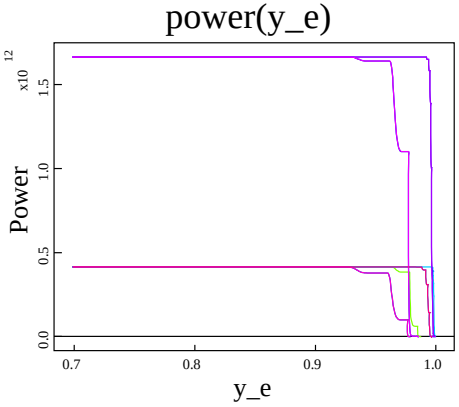








CQL3D Fokker- Planck Code

- Calculates the distributions $f_{e,i}(u_{\|}, u_{\perp}, \rho\ t)$ of electrons and/or ions resulting from Coulomb collisions, RF QL diffusion, toroidal E_{dc}, NBI, and radial transport.

- Ray data from GENRAY gives QL diffusion data.

- Uses full non- linear 2D Coulomb collision operator and full Stix QL diffusion operator.

- Applied to EBW, EBWCD efficiency is 0.07A/W for the central CD in 6e13 cm^{-3}, 3 keV NSTX plasma. This is efficiency $\eta = 0.04\ x 10^{20} \mathrm{m}^{-2}\mathrm{A}/W$. Optimizations are yet to carried out.

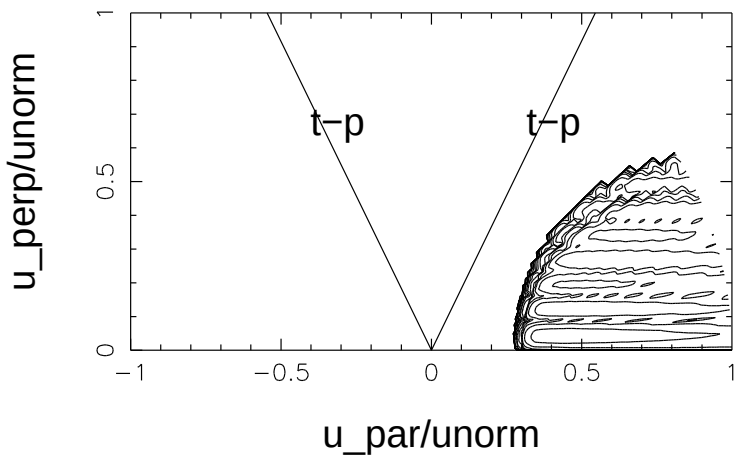
- **Following slides show the QL diffusion coefficient, f_e at intermediate radius, and the radial profiles of deposition and CD.**

CQL3D EBW QL Diffusion Coeff and Resulting Electron f_e(u,theta).

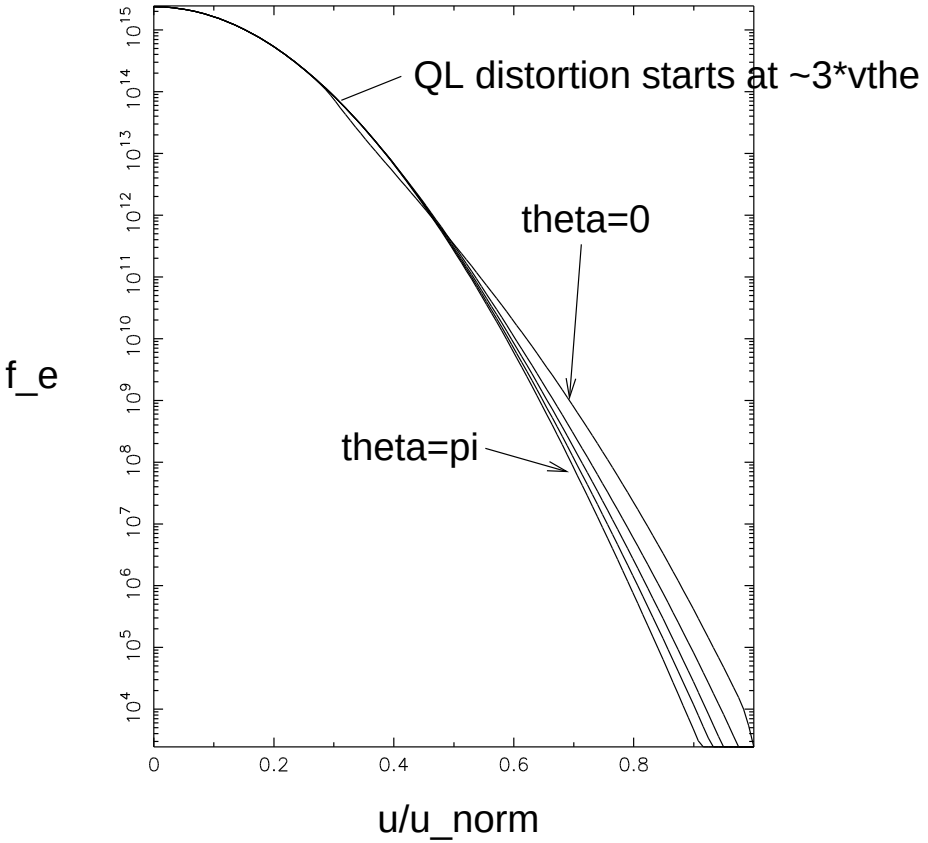
(For one of 21 flux surfaces.)

r/a=0.15
unorm such that Enorm=100 keV
vthe/unorm=0.11

QL Diffusion Coefficient



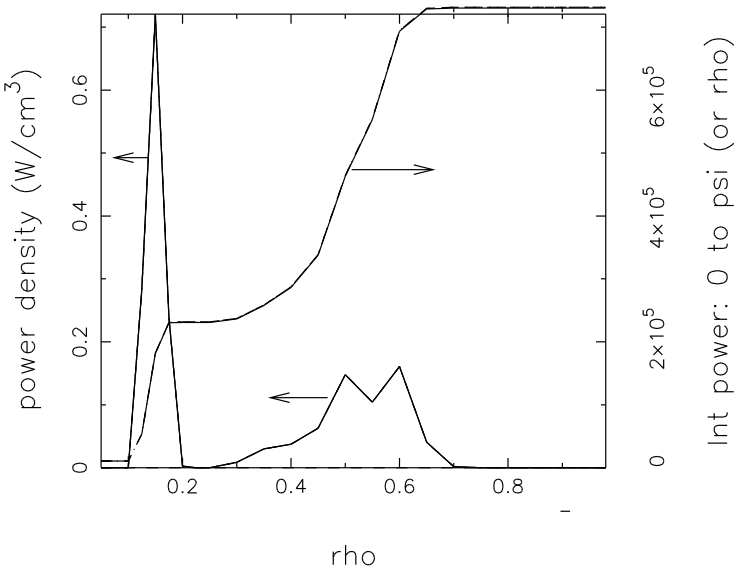
Cuts of f_e(u,theta) vs u



EBW Power Deposition and Driven Current

***Above midplane launch case.**
***Current is driven near the axis in negative dirn and at intermediate radii in the positive dirn, due to n_par variation.**
***CD efficiency near the axis is 0.07 A/W, giving efficiency eta=0.04 (not optimized).**

Power Density (Watts/cc) and
Integrated Power (Watts)



Current Density (A/cm**2) and
Integrated Current Density (Amps)