Centrifugal Mirror Fusion Experiment (CMFX)

UMBC AN HONORS UNIVERSITY

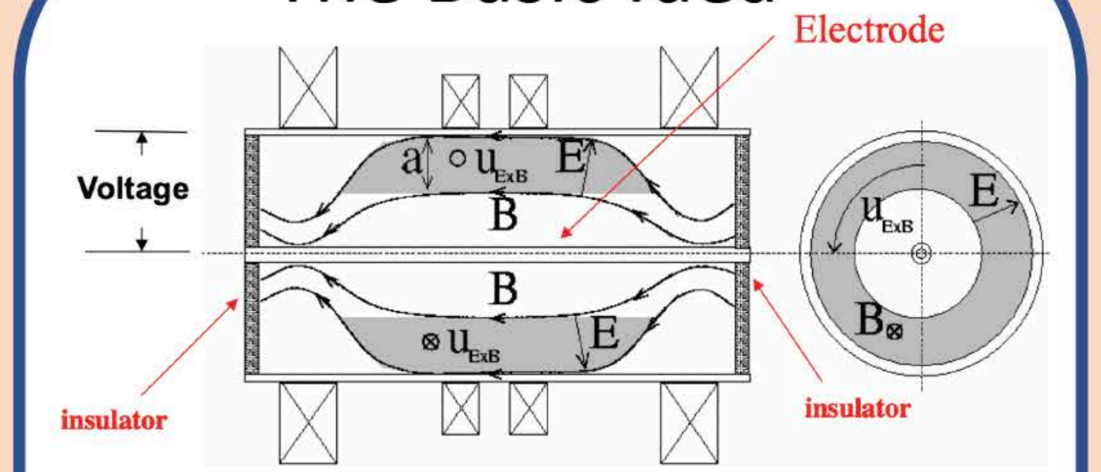
Work supported by arpa·e
Under award no. DE-AR0001270
Special thanks to AFRL for equipment donation, and MSGC for supporting students.

C. A. Romero-Talamás[1,2], A. B. Hassam[2], B. Beaudoin[2], I. Abel[2], T. Koeth[2], D. Basu[1], N. Eschbach[1], N. Schwartz[2], Z. Short[2], M. Kelly[2]

[1]Department of Mechanical Engineering
UMBC, Baltimore, Maryland 21250

[2]Institute for Research Electronics and Applied Physics
UMCP, College Park, Maryland 20742

The Basic Idea



MHD Model

For a rotating plasmas in equilibrium and with collisions:

$$nM\left(\cancel{\frac{\partial u}{\partial t}}^{0}+\mathbf{u}\cdot\nabla\mathbf{u}\right)=-\nabla p+\mathbf{j}\times\mathbf{B}-nMv_{\rm in}\mathbf{u}$$

Radial currents balance collisional losses

$$(\mathbf{j}\times\mathbf{B})_\phi=j_\psi B=nMv_{\rm in}u_\phi$$

Azimuthal currents balance thermal pressure:

$$(\mathbf{j}\times\mathbf{B})_\psi=j_\phi B=\nabla p_\psi=nM\mathbf{u}\cdot\nabla\mathbf{u}$$

Taking only components parallel to B:

$$\mathbf{B}\cdot\nabla p=\mathbf{B}\cdot(nM\mathbf{u}\cdot\nabla\mathbf{u})$$

And substituting: $\mathbf{u}=R\Omega\hat{\phi}$

Such that: $\mathbf{u}\cdot\nabla\mathbf{u}=\nabla\left(R^2\Omega^2/2\right)$

And **assuming T = const**:

$$\frac{\mathbf{B}\cdot\nabla n}{n}=\mathbf{B}\cdot\nabla\left(\frac{R^2\Omega^2}{2c_s^2}\right)$$

Integrating and evaluating at R_{min} and R_{max}:

$$\frac{n_{\rm Mid}}{n_{\rm End}}=\exp\left[\frac{\left(R_{\rm Mid}^2-R_{\rm End}^2\right)\Omega^2}{2c_s^2}\right]$$

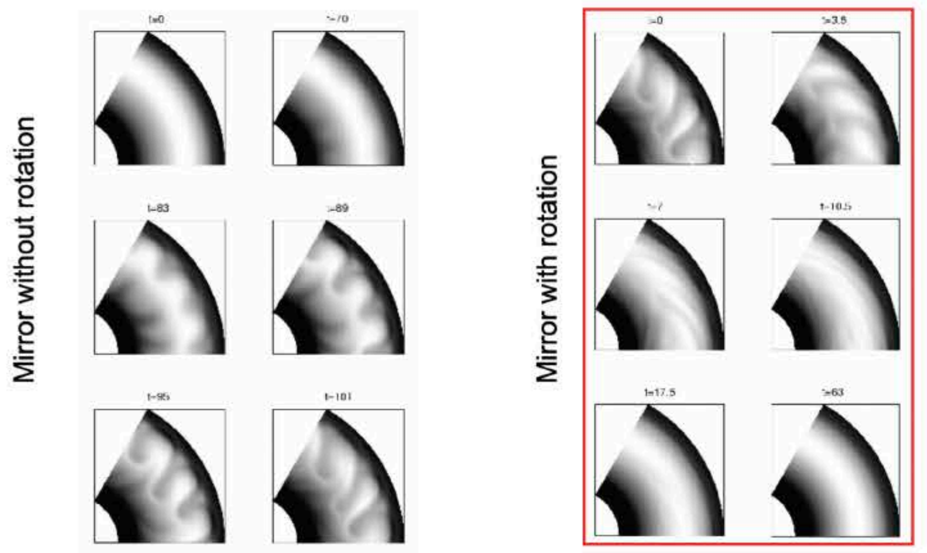
Let: $M_s=v_\phi/c_s$

$$\boxed{\frac{p_{\rm Mid}}{p_{\rm End}}=\exp\left[\frac{M_s^2}{2}\left(1-\frac{1}{R_A^2}\right)\right]}$$

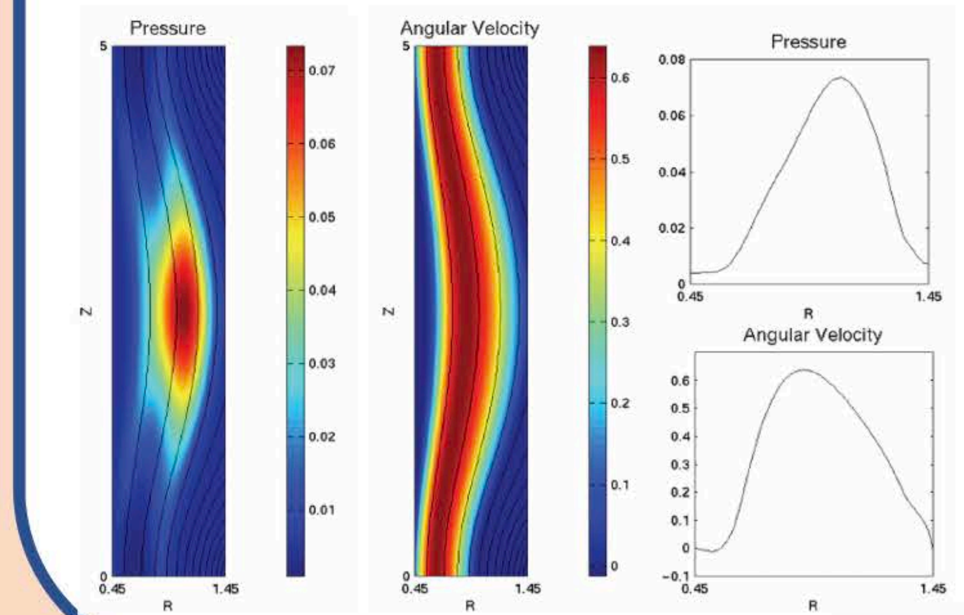
Where $R_A = B_{max}/B_{min}$.

Interchanges occur at sonic times;
To suppress interchanges: $M_s > 1$

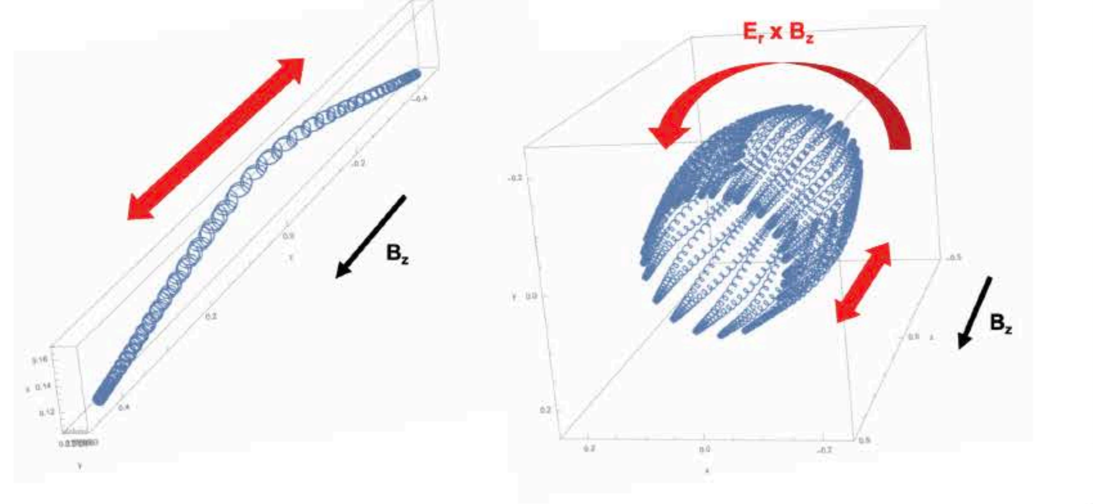
MHD Simulations



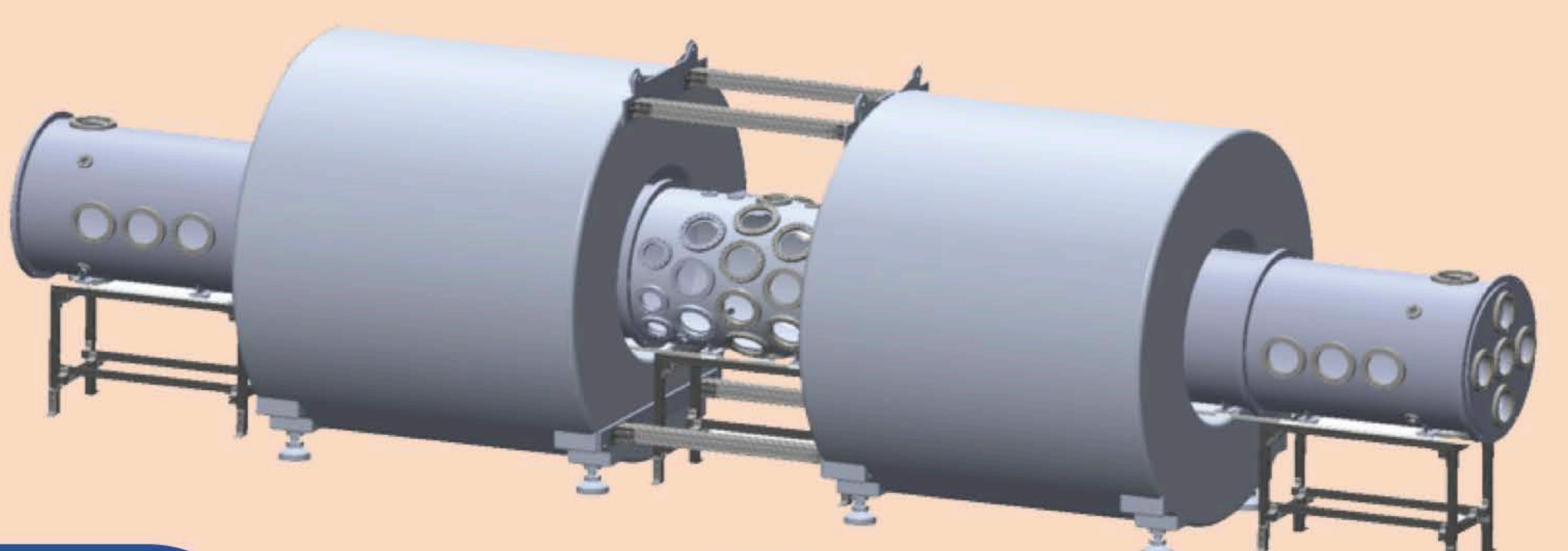
Simulations demonstrate centrifugal confinement



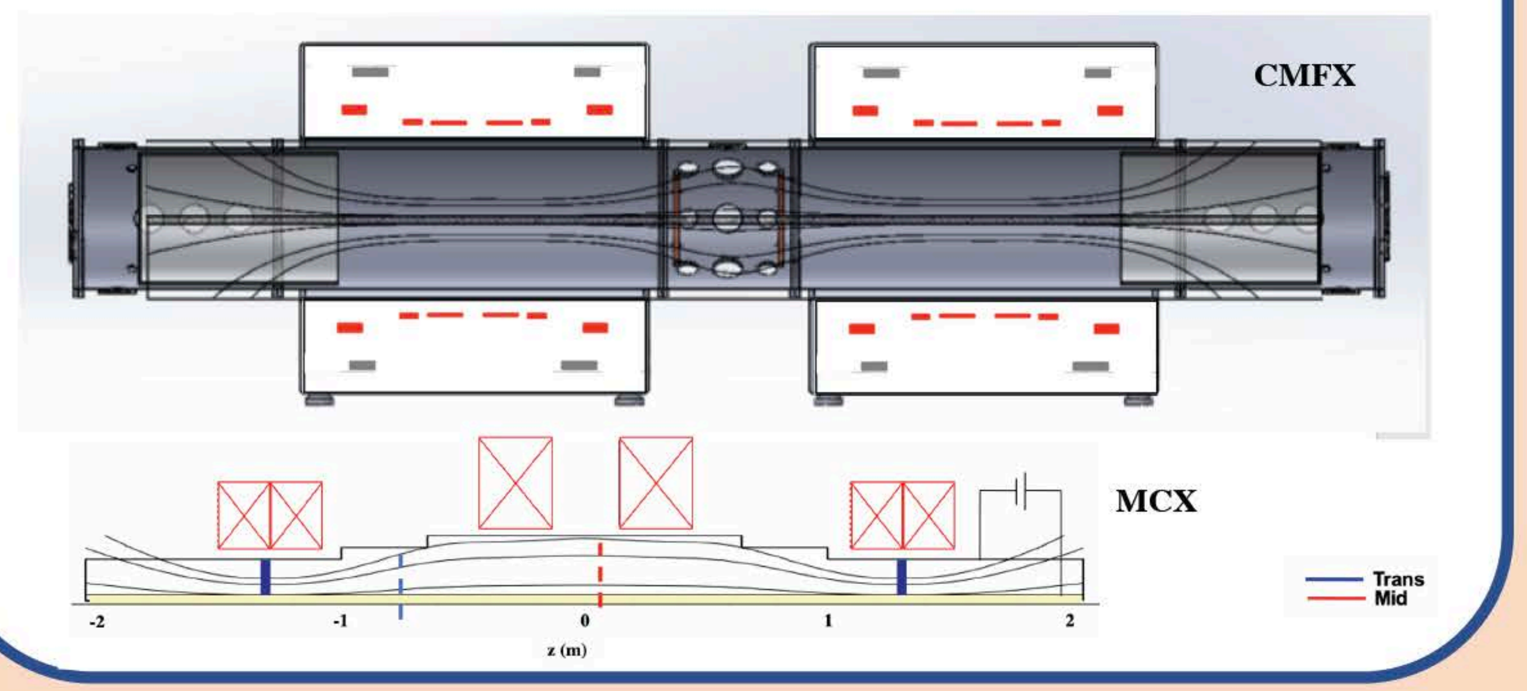
High magnetic field for the mirrors, moderate field for rotation, and high voltage at the center is required to suppress interchange modes in this steady state thermonuclear fusion concept



Mirror without rotation **Mirror with E_r and rotation**

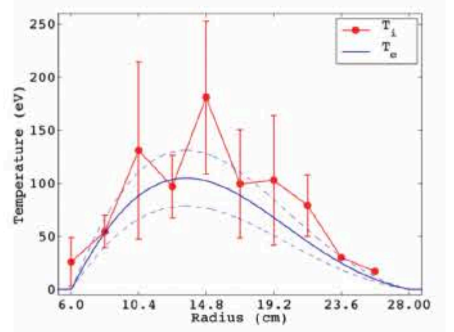


CMFX will be the first superconducting, supersonic, rotating plasma experiment. It builds on the results obtained from the Maryland Centrifugal Experiment (MCX). CMFX has a wider range of experimental parameters.

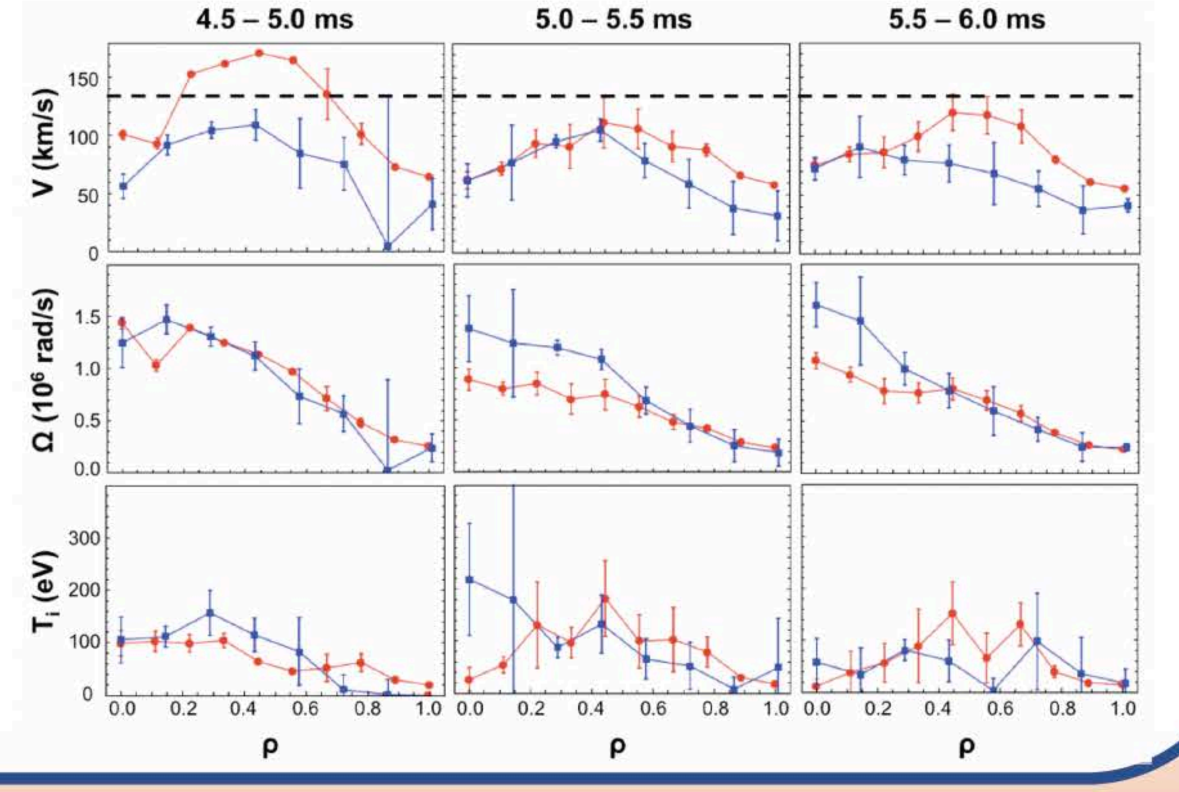


It is the second iteration and builds on the results obtained from the Maryland Centrifugal Experiment (MCX). CMFX has a wider range of experimental parameters in density, field shape, and field strength, as well as improved vacuum conditions. MCX achieved supersonic rotation and overcame (briefly) the critical ionization velocity limit (CIV).

V_{CIV} at midplane = 50.9
x $7^{1/2}$ = 134.7 km/s



T_i and T_e in MCX.

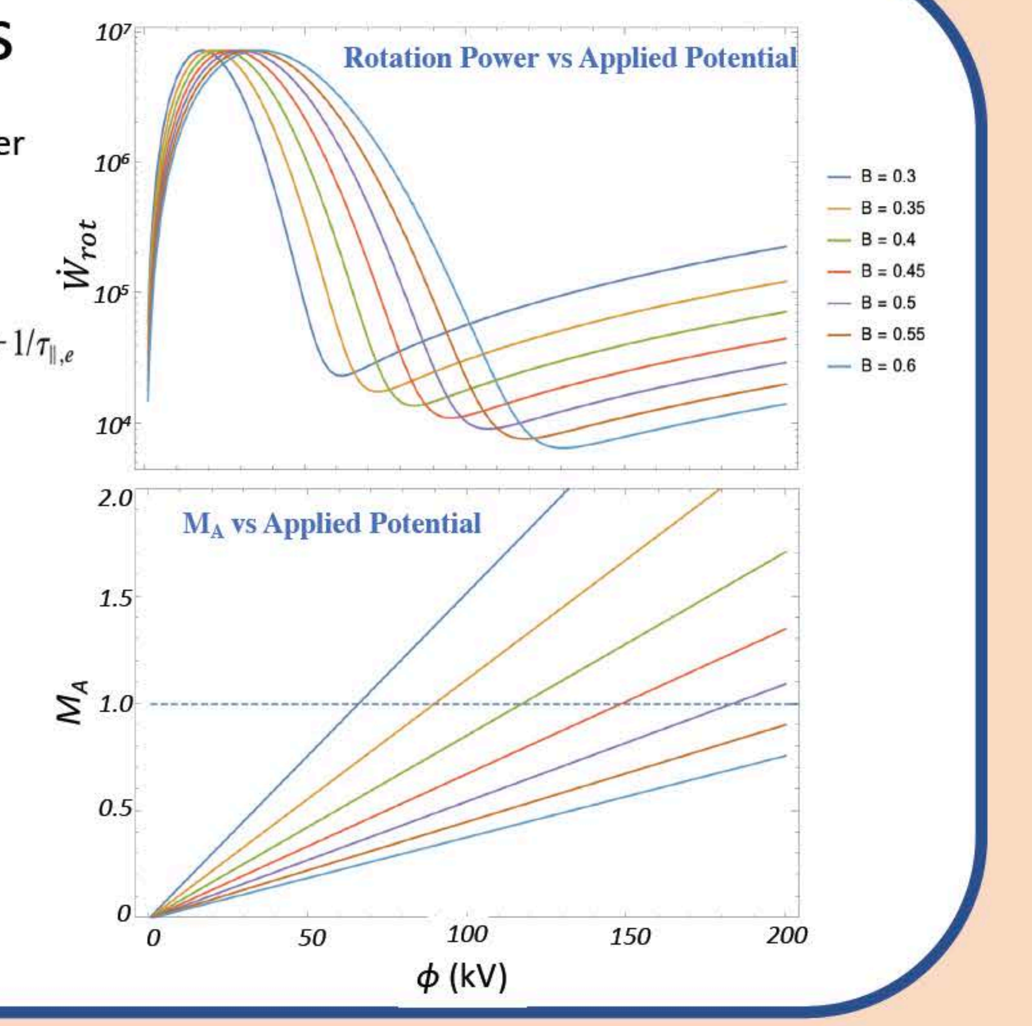


0-D Power Calculations

Maintaining supersonic rotation requires higher power than Bremsstrahlung and charge exchange losses

Rotation needs to be maintained against dissipation
Dissipation ends up as heat: $NMu_T^2/\tau_{\rm mom}=IV_0$
Where $1/\tau_{\rm mom}=1/\tau_{\rm CX}+1/\tau_{\perp,i}+1/\tau_{\parallel,i}$ and $1/\tau_{\rm heat}=1/\tau_{\rm CX}+1/\tau_{\perp,i}+1/\tau_{\parallel,e}$
and $\tau_{\perp i}\sim a/(\rho_i^2\nu_{ii})$ and $\tau_{||e}\sim \nu_{ee}^{-1}\exp[M_s^2/4]$

- CMFX plasma : a cylinder, $a = 0.25$ m, $L = 1$ m
- $K.E.=\frac{1}{2}I_c\Omega^2$ with $I_c=\frac{m}{2}(r_1^2+r_2^2)$
- D-D plasma at 0.5 keV
- $n=1\times10^{19}\ m^{-3}$
- Total fusion power: 0.5 W.
- At low densities, well within $M_A < 1$ constraint for minimum power requirement.
- If $\varphi = 100\ kV$ and B = 0.5 T then
  - $\dot{W}_{rot}=11\ kW$
  - $\dot{W}_{Bremstr}=6\ W$
  - $Q_{sci}=5\times10^{-5}$

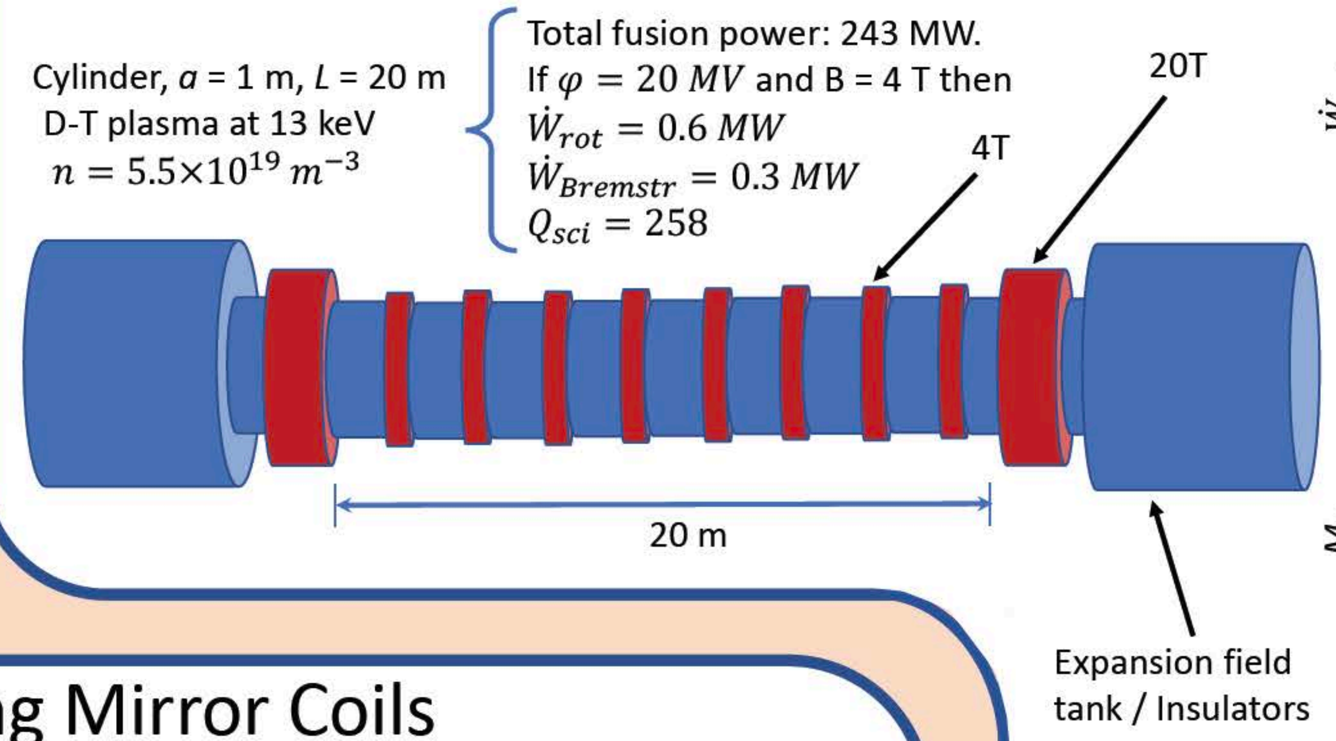


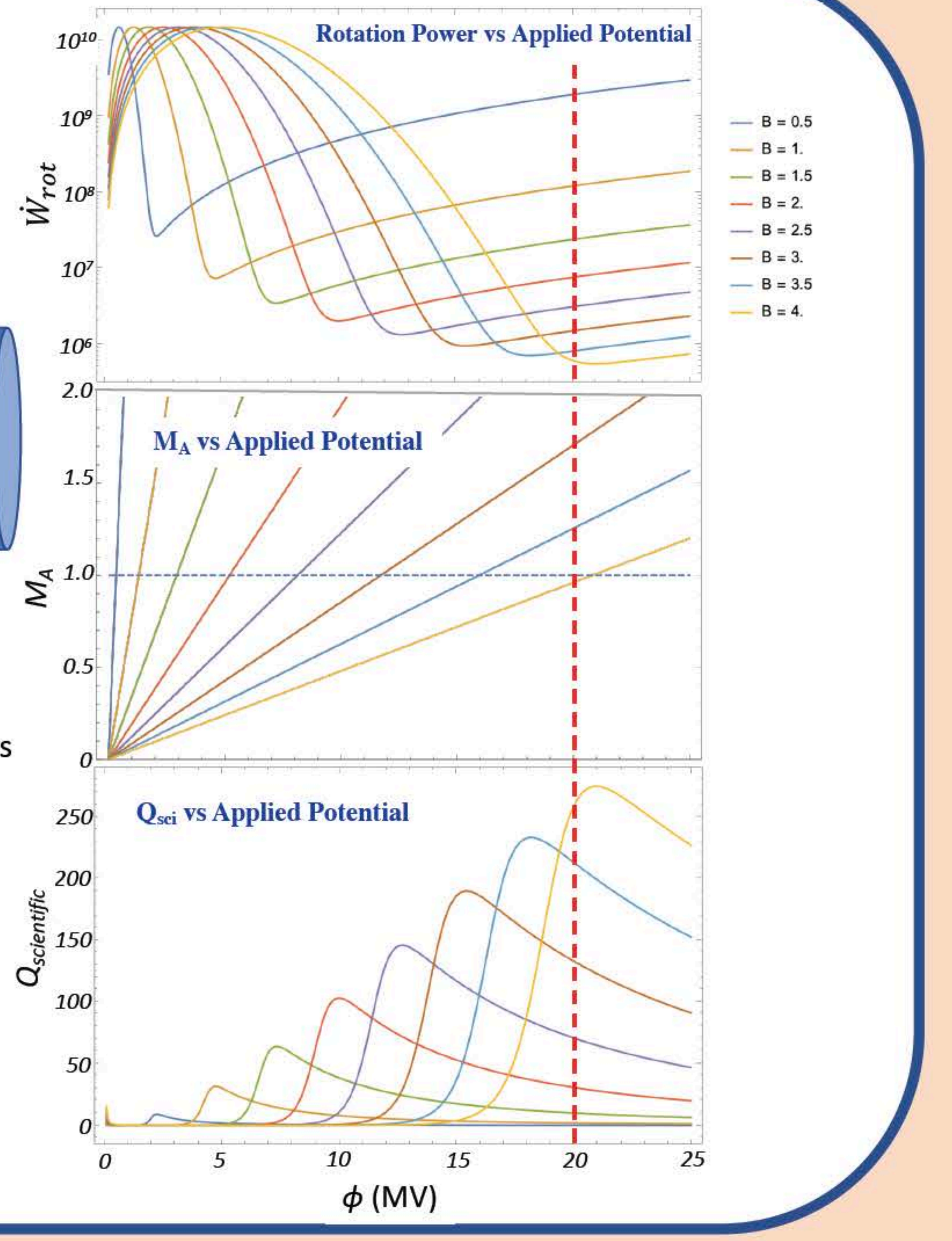
D-T Reactor Scenario

Preliminary estimates show LCOE of ~$0.075/kWh for this scenario

Cylinder, $a = 1$ m, $L = 20$ m
D-T plasma at 13 keV
$n=5.5\times10^{19}\ m^{-3}$

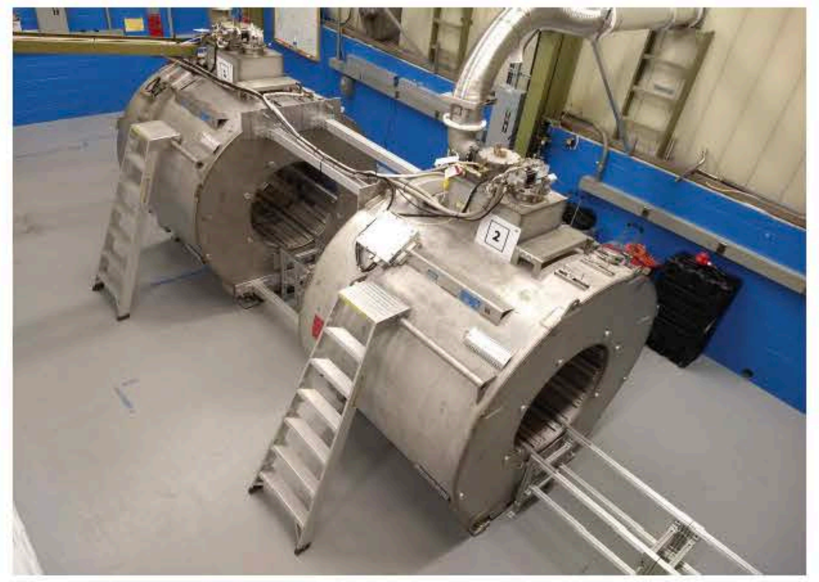
Total fusion power: 243 MW.
If $\varphi = 20\ MV$ and B = 4 T then
$\dot{W}_{rot}=0.6\ MW$
$\dot{W}_{Bremstr}=0.3\ MW$
$Q_{sci}=258$

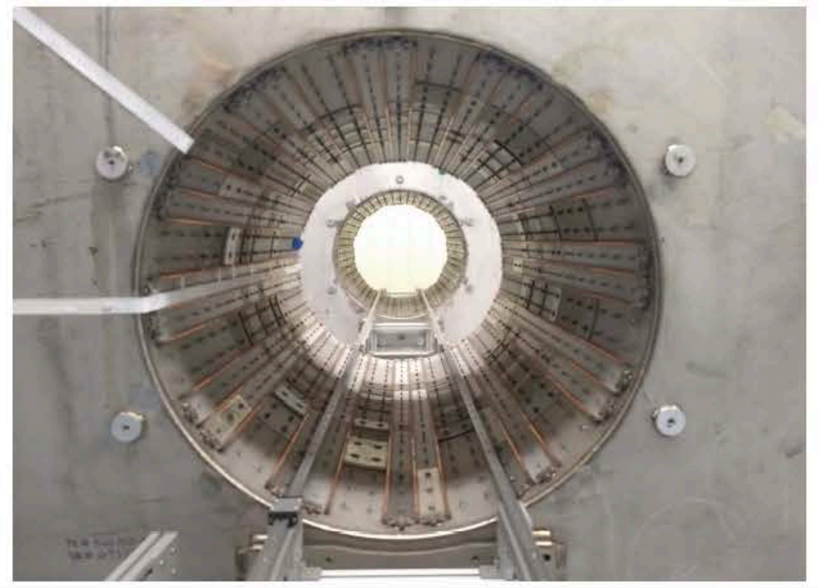




Superconducting Mirror Coils

Magnets are aligned and ready to receive chamber and electrodes. Magnets tested individually at 3-T each.





Selected references
[1] Hassam, AB, Comments Plasma Phys Cont. Fus., **18**, 263, 1997.
[2] Ellis, RF; Hassam, AB; Messer, S; et al. *Phys. Plasmas* **8**, 2057, 2001
[3] R. Lunsford. Ph.D. Thesis, U. of Maryland, Ch. 1 (2007).
[4] Yi-Min Huang and A. B. Hassam, PRL **87**, 235002 (2001).
[5] R. R. Reid, C. A. Romero-Talamás, W. C. Young, R. F. Ellis, and A. B. Hassam, *Phys. Plasmas* **21**, 063305 (2014).
[6] C. A. Romero-Talamás, R. C. Elton, W. C. Young, R. Reid, and R. F. Ellis, *Phys. Plasmas* **19**, 072501 (2012).