Potential of Magnetic Mirrors

Development of Fusion Energy Science: Physics, Materials, Blankets

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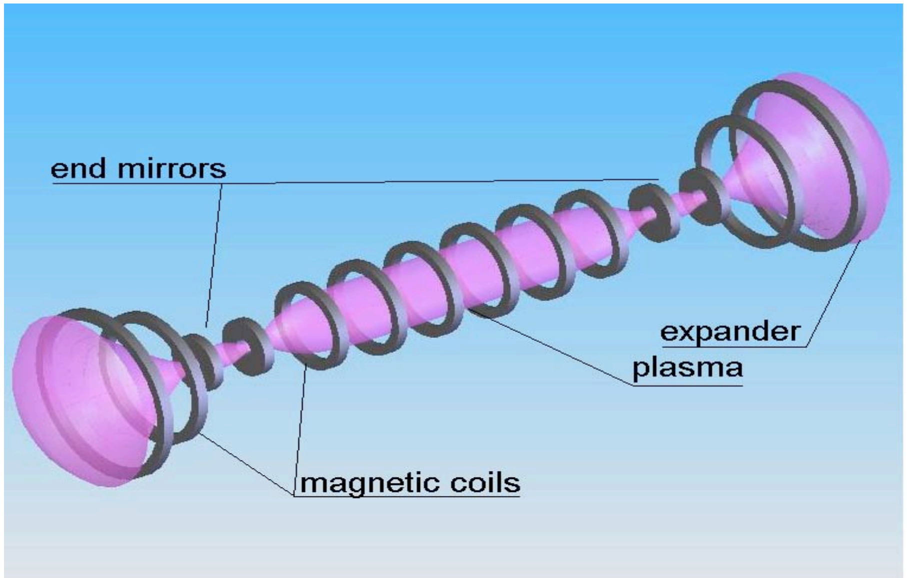
What is New?

- Data from Russia
  - Axisymmetric Concept
- Material Science Mission
- First Principles Simulation and Validation

Axisymmetric Mirrors



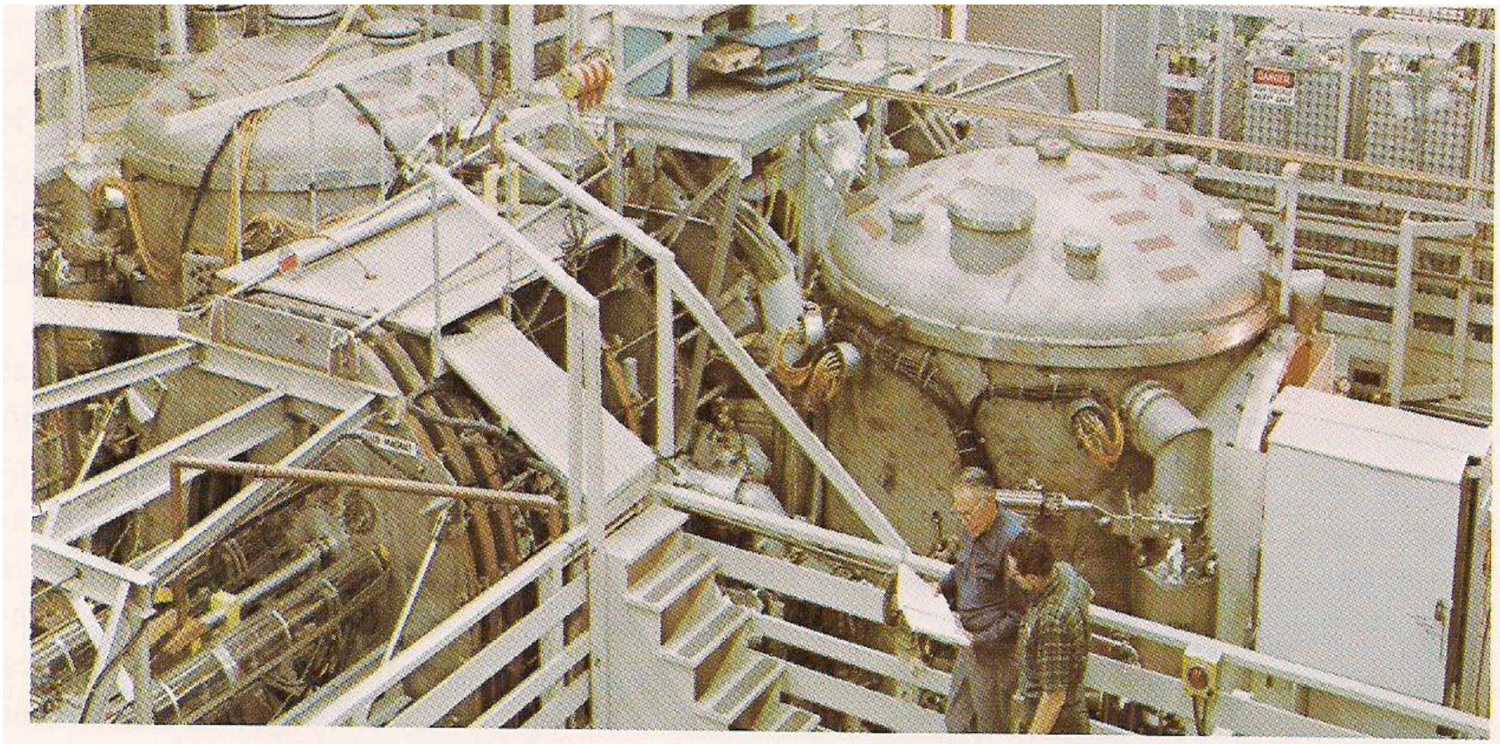
- Circular Coils without Thermal Barriers
  - Simplified Engineering and Physics
    - No neoclassical radial transport
    - High mirror ratio and Natural Divertor
    - Ease of Construction and Maintenance

A Simple Mirror can be MHD Stable

- **Seven Tested Methods**
  1. **Expander plasma Outflow (GDT)**
  2. **Plasma Rotation (MCX)**
  3. **Divertor(Tara)**
  4. **Pondermotive (Phadrus & Tara)**
  5. **End Wall Funnel Shape (Nizhni Novgorod)**
  6. **Line-Tying (UCBerkeley)**
  7. **Cusp End Plugs (GDT)**

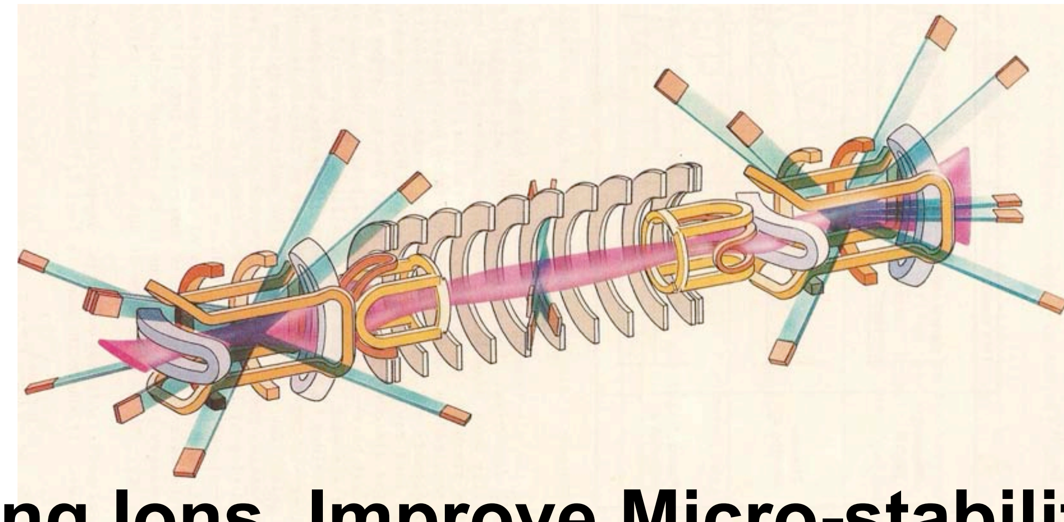
- **Four Untested Methods**
  1. **Kinetic Stabilized Tandem Mirror (Post)**
  2. **Pulsed ECH Dynamic Stabilization (Post)**
  3. **Wall Stabilization & Feedback (Berk)**
  4. **Non-paraxial End Plugs (Ryutov)**

2XII-B Beta=70% Ei = 10 keV



- Te=140 eV with Stream Stabilized DCLC Nonlinear Stability
- Reactor Study Q ~ 1

TMX-U Tandem Mirror



Sloshing Ions Improve Micro-stability

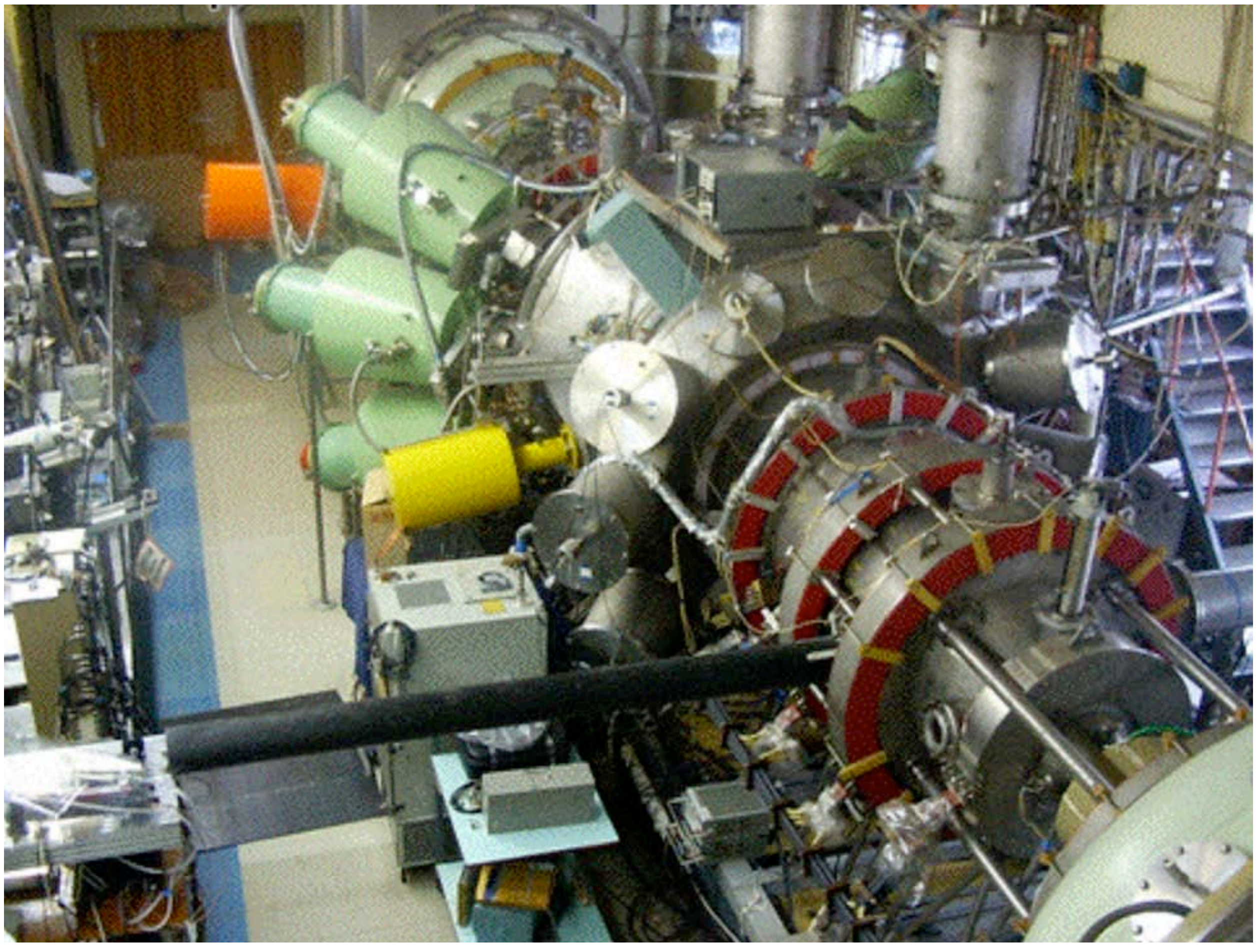
Te < 280 eV ,   tau-e ~ 100x that of 2XIIB

Reactor Q > 10 but complex Thermal Barrier

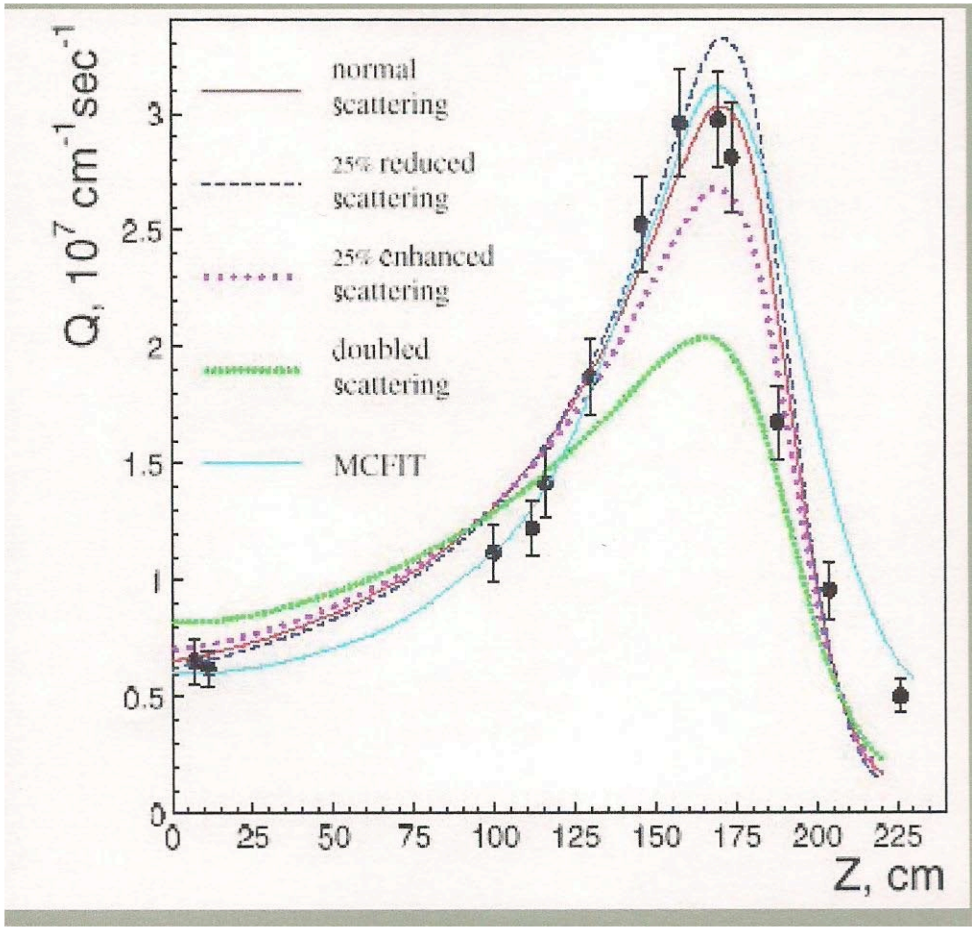
Thermal Barrier Confinement only at Low ne

GDT - Novosibirsk, Russia

60% Beta, Ei ~ 10 keV, Te < 230 eV

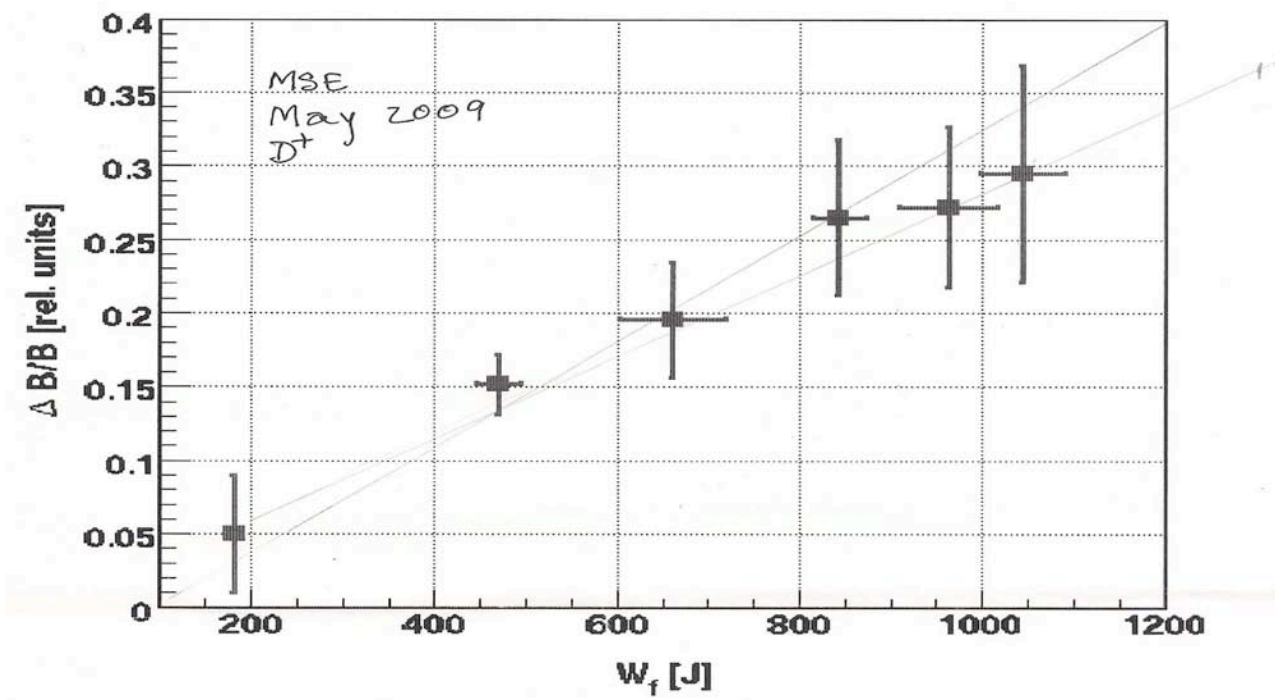


GDT DD Neutron Axial Profile Agrees with Theory



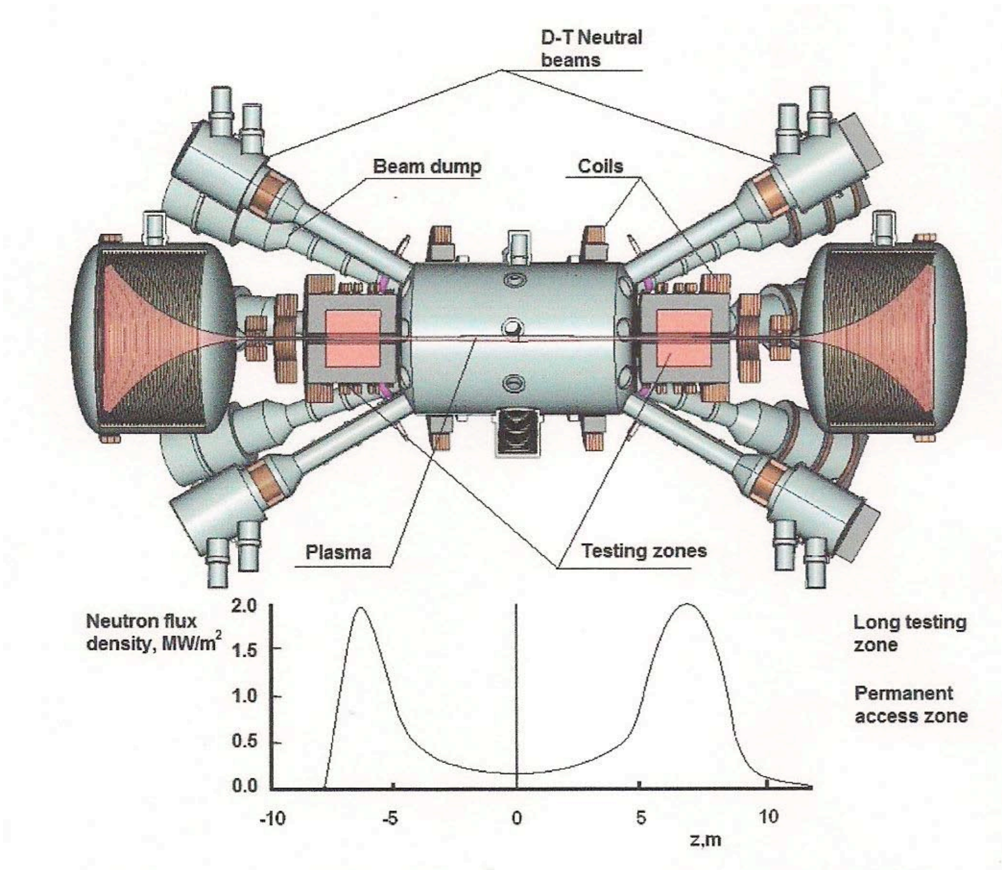
MSE Measurement of Beta

Delta B versus Plasma Energy



- **50% Normalized to Vacuum Magnetic Field**
- **100% Normalize to Depressed Magnetic Field (FLR)**

A 14 MeV Neutron Source to Qualify Materials & Subcomponents



Mirror Neutron Source Characteristics

- **Compared to IFMIF-like Point Sources**
  - \+ 100x larger test volume
  - \+ True 14 MeV Neutron Energy Spectrum
  - \+ Potential for simultaneous neutron and plasma-wall interaction testing

Compared to Tokamak Volume Sources

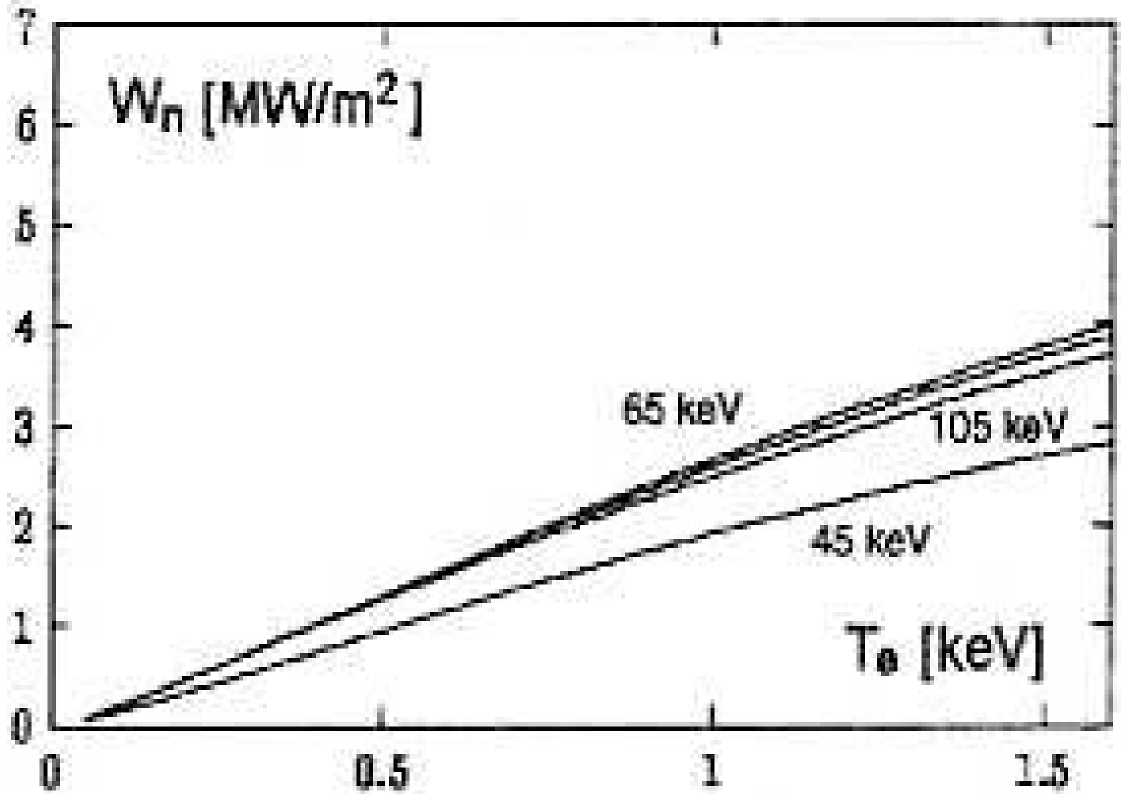
\+ burns 100x less tritium

\- 100x smaller test volume

Neutron Flux Increases With Te

(for various NBI energies)

Today's Te ~ 0.2 keV would produce ~ 0.3 MW/m2



A Development Path

- GDT Collaboration (~ 2 M$)
  - 20 keV – 5 ms NBI & 0.3/6.5 T Magnetic Field
  - Theory & Simulation
  - Diagnostics
- Next Step Collaboration (~ 10 M$)
  - 40 keV – 1 sec. NBI & 1 T Magnetic Field
- Neutron Source Hydrogen Prototype Collaboration (~ 40 M$)
  - 80 keV - ss NBI & 2 T Magnetic Field

A Development Path

Parameter	GDT	Next Step	Neutron Source
L, m	8	11	11
a, m	0.18	0.2	0.2
B(min), T	0.3	1.0	1.8
B(max), T	6.5	12	20
NBI, keV	20	40	80
NBI, MW	4	10	30
Duration, s	0.005	1	ss

Potential Scientific Value

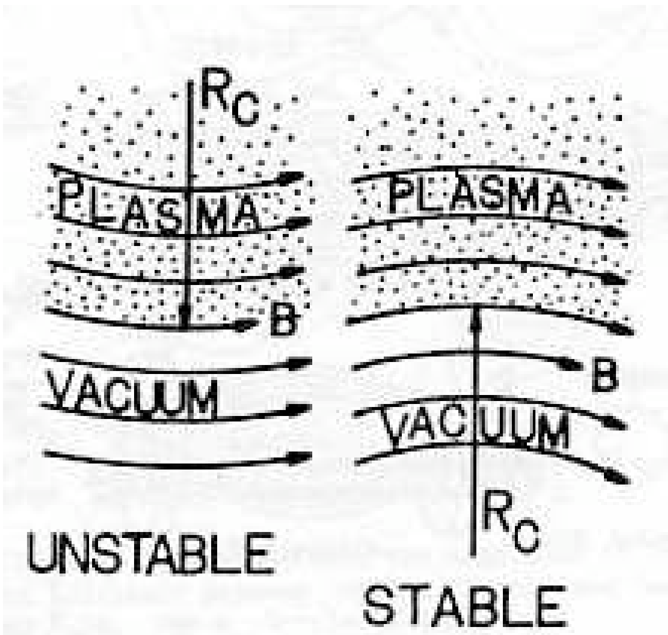
Validate Predictive Simulation

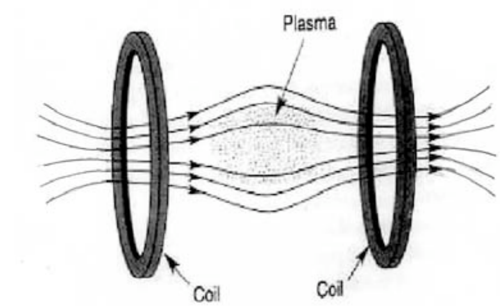
- Eb/Te similar to ITER Alpha Particle Ratio
- Open Field-Line Divertor Physics
- Vortex ExB-shear Analogous to Tokamak Second –Stability B-shear and H-mode
- Nonlinear Velocity Space Flattening Analogous to Toroidal Radial Flattening
- Unity Beta, Vortex, Micro-Turbulence connections to Space and Astrophysics

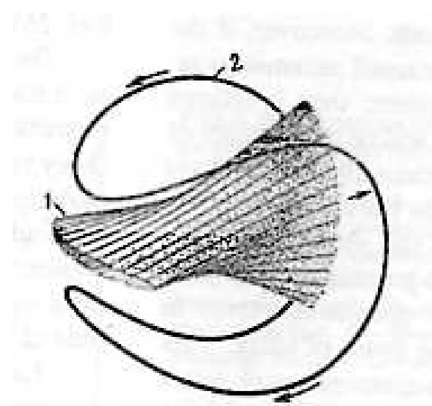
Backup

Minimum-B Magnetic-well is MHD Stable

Simple Mirror is MHD Unstable







Vortex Shear Flow MHD "Stabilization"

A.D. Beklemishev, Varenna 2008

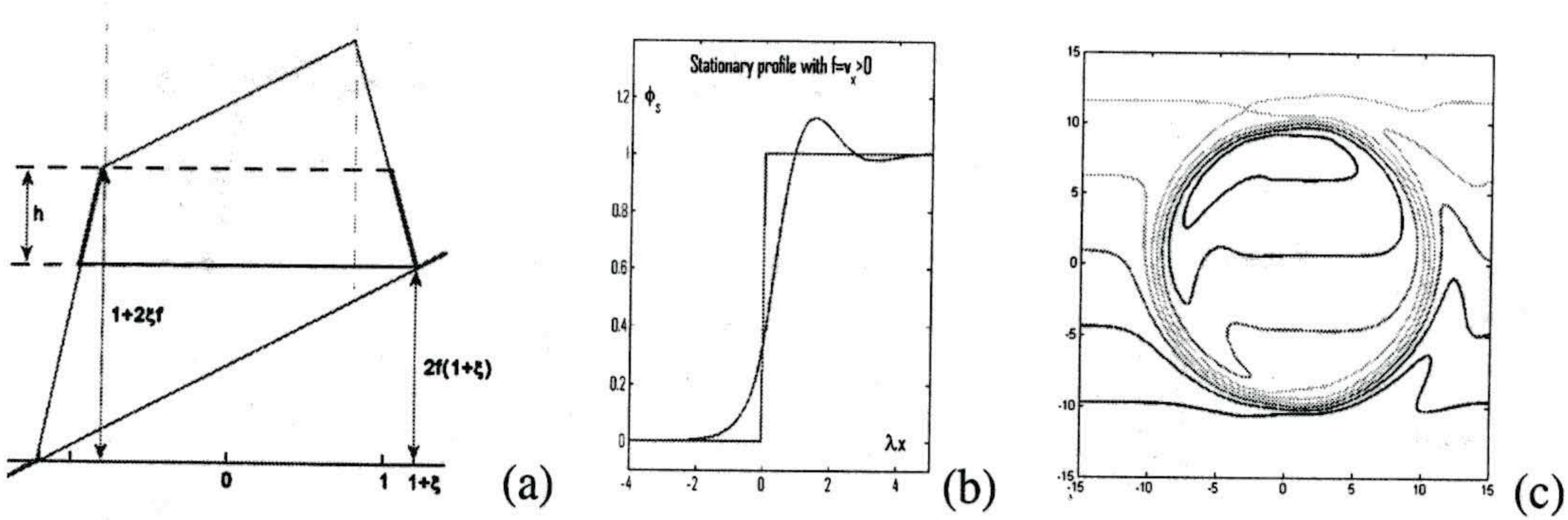
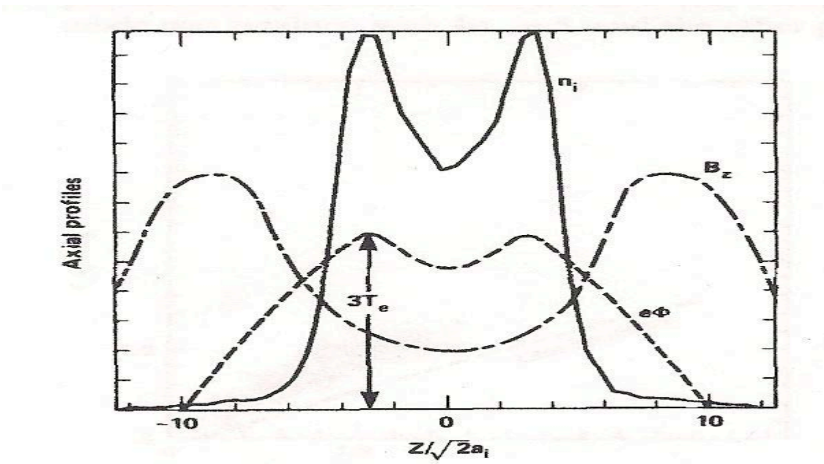
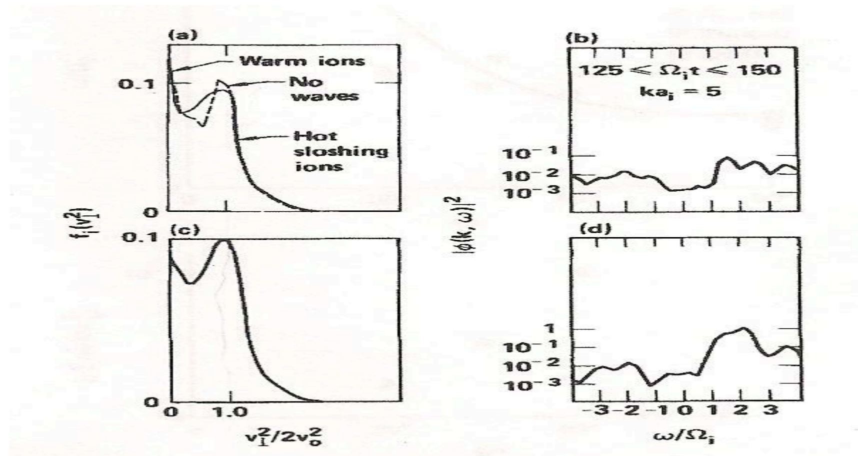


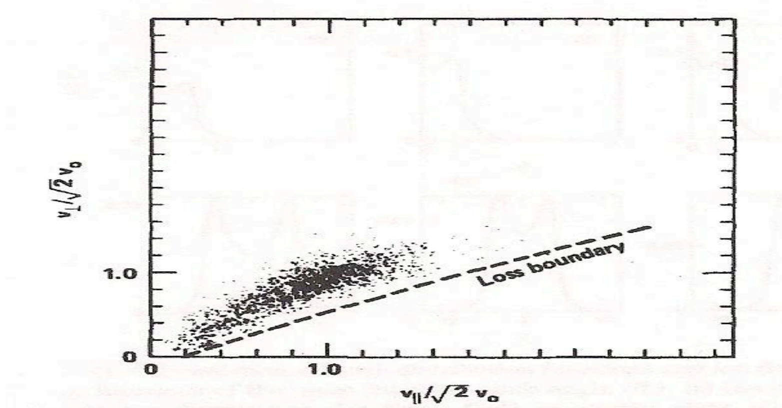
FIGURE 6. (a) Scheme of the vortex potential profile perturbed by the "rigid" $m = 1$ mode, which generates a quasi-uniform transverse "wind-field", $f = f_0 \cdot r cos\theta$. The flow-lines in the region $h > 0$ remain closed, if the perturbation amplitude is lower than the vortex amplitude, $2f_0 < 1$. (b) Potential profile in the perturbed flow-layer (slab). (c) Flow-lines in cylindrical geometry.

DCLC Simulation of Sloshing Ions

Bruce Cohen et. al. Phys. Fluids 27, (1984), 642







- **Te Increases Loss -Cone Size**
- **Loss-Cone Drives Turbulence**
- **Turbulence Drives Plasma loss**
- **Plasma Loss Decreases Te**
- **To Increase Te Increase Beam Energy to keep Similar Size Loss-Cone (Te ~Eb/)**