# Progress and Plans for FRC Studies in MRX-FRC

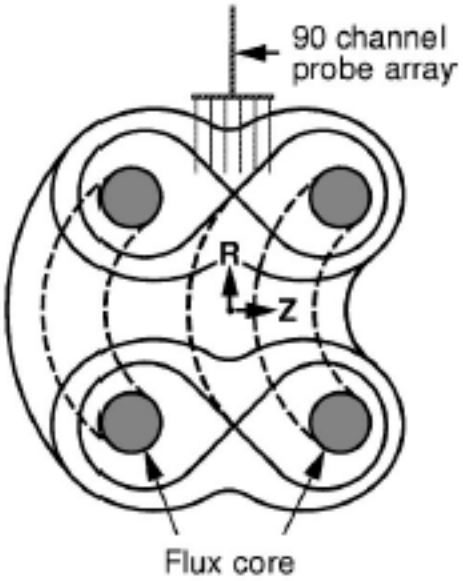
Presented by Stefan Gerhardt, representing
the MRX-FRC team.

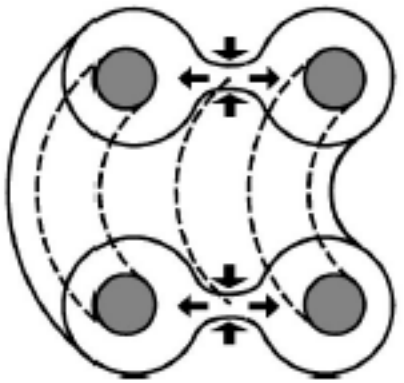
# Outline

- Introduction to MRX
- Three Stages of MRX-FRC
  - Merging and Conducting Shell Stabilization
  - Current Amplification and Sustainment with Transformers
  - Stabilization and Sustainment with NBI
- Diagnostics and Summary

# MRX is an Established Facility for Reconnection Studies

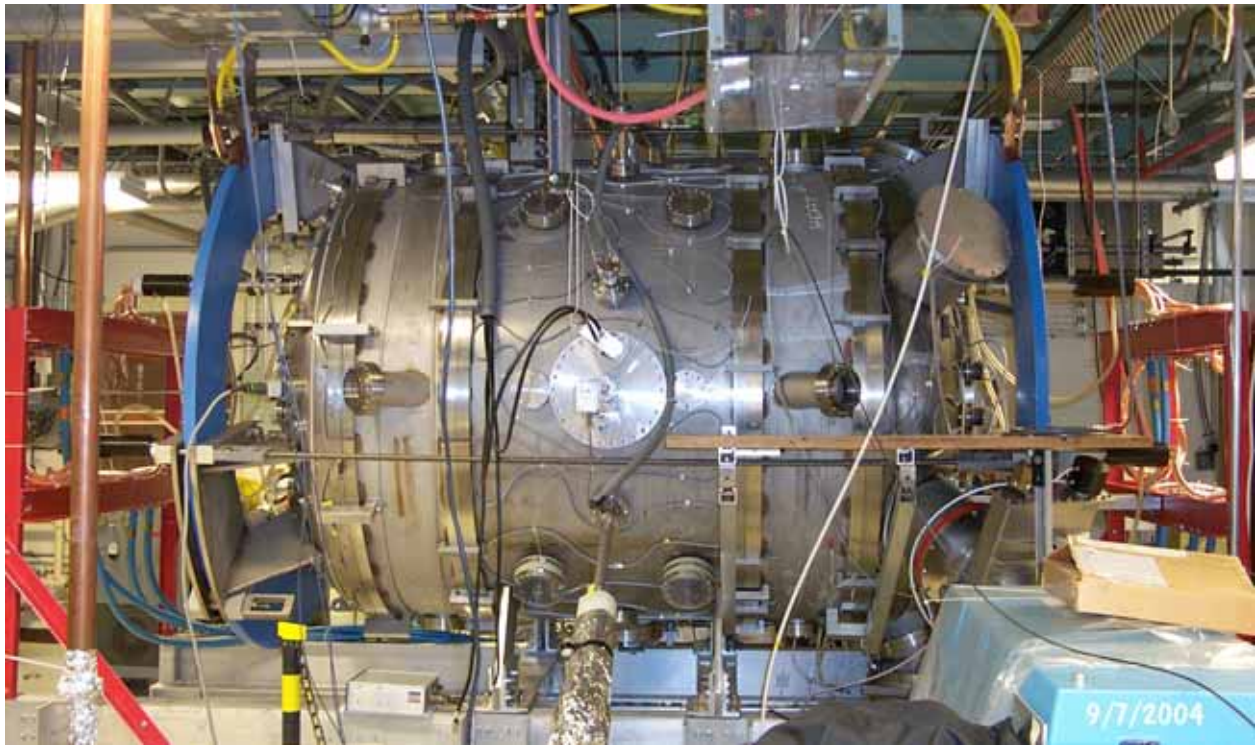
- Two Co-axial Flux Cores Form a reconnecting Current Sheet
- Focus Till Now on Local Physics of Reconnection
  - Verified a generalized Sweet-Parker Model of reconnection
  - Measured the LHDI in at the current sheet edge.
  - Measured Magnetic Fluctuations near the LH frequency which correlate with fast reconnection.
- Beginning Studies of Global Reconnection and Spheromak Merging



# Much of 2004 has been Occupied with Facility Upgrade

- Relocated the PF and TF power supplies, increased stored energy (250kJ), decreased stray inductance.




- Extended vacuum vessel to allow greater flux-core separation

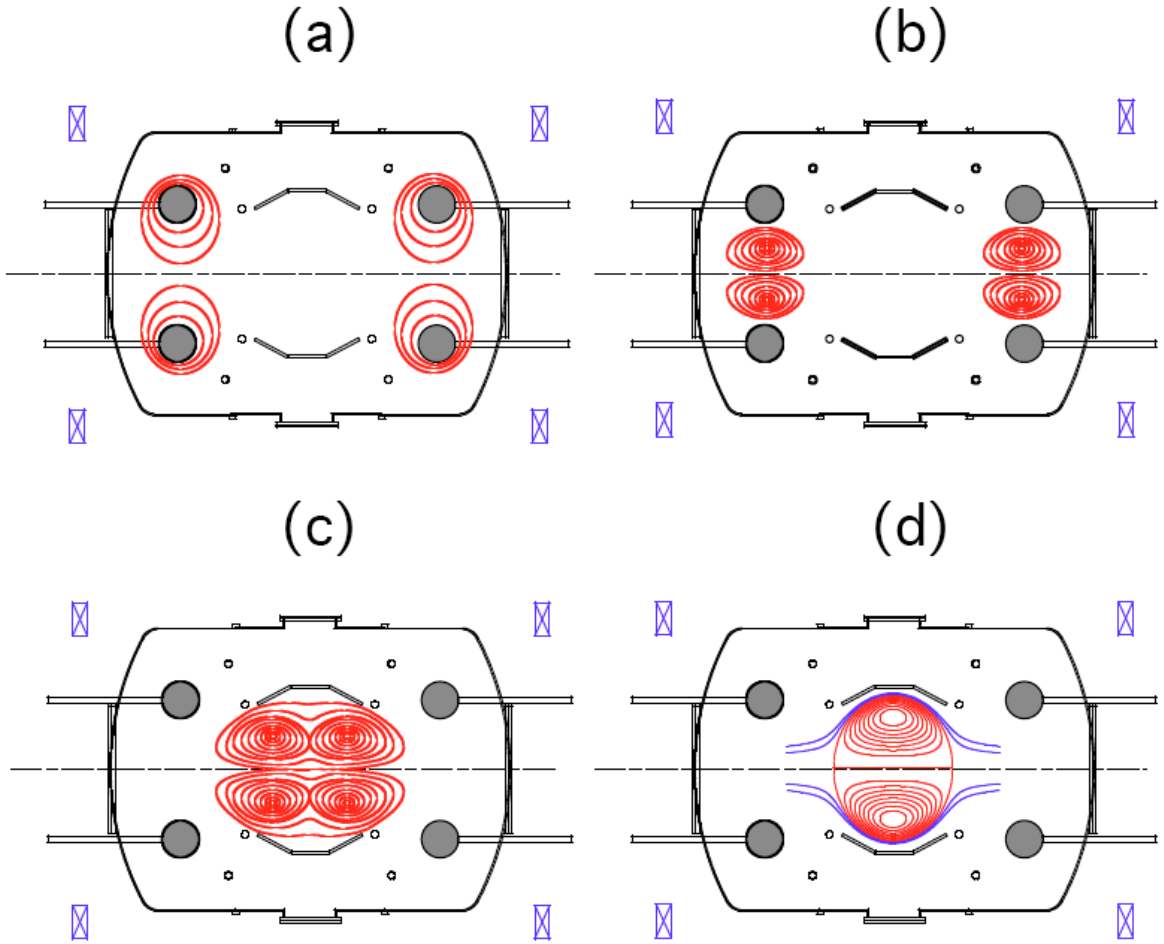
# Stage 1: FRC Formation and Conducting Shell Stabilization

(a) Plasma Formation

(b) Spheromak Pinch-Off

(c) Spheromak Merging

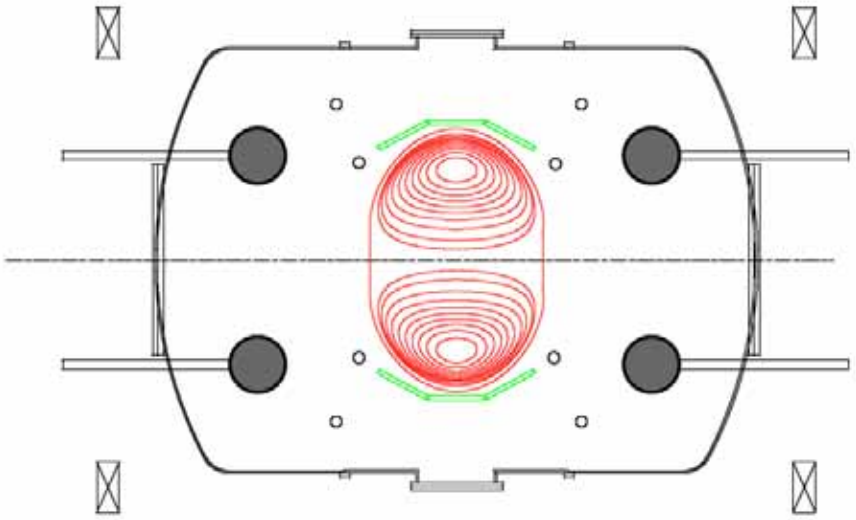
(d) Final FRC State



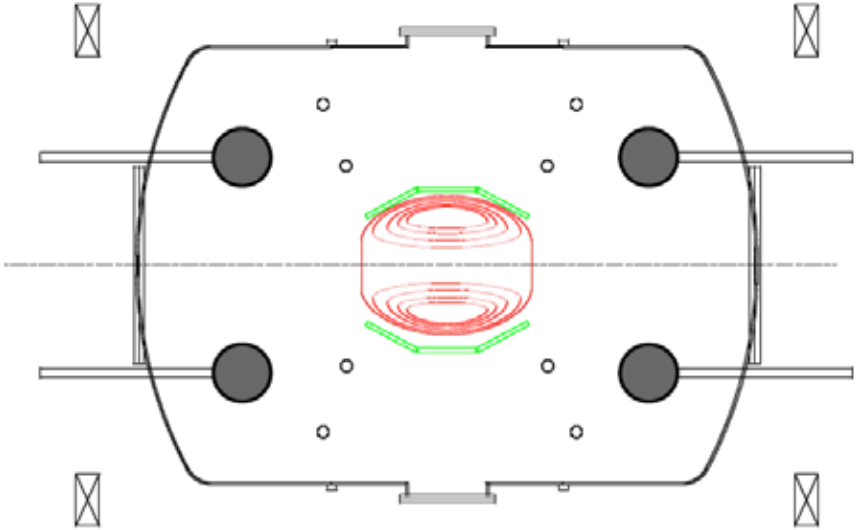
# Experimental Flexibility Provided by Adjustable Conducting Structures

- First test of Conducting Shell Stabilization for FRCs
- Movable without breaking vacuum
- Shell location and EF used to change elongation.

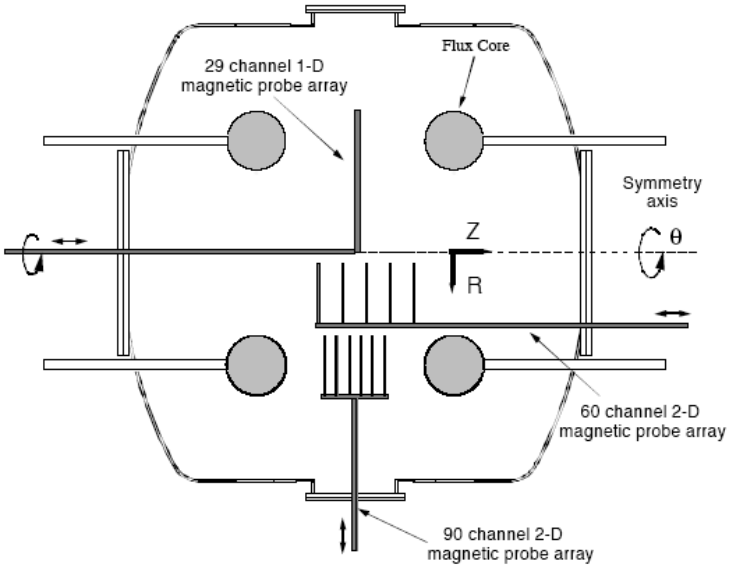
**E≈0.5**

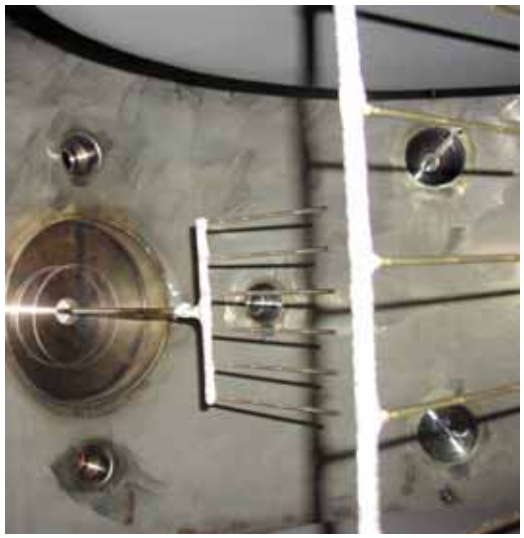


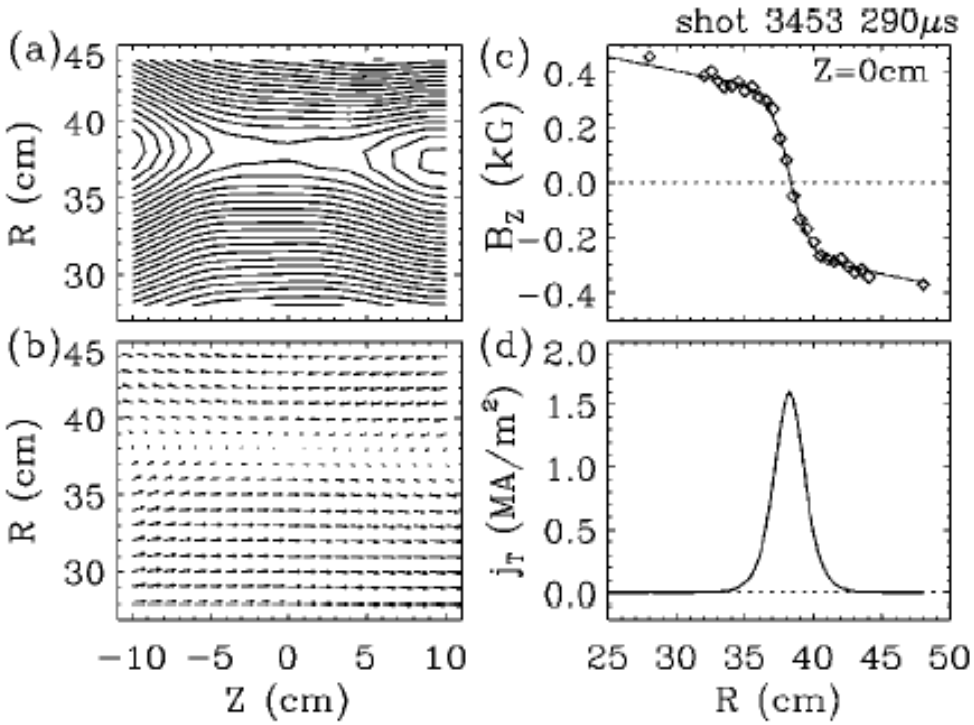
**E≈1.5**



# Extensive Internal Magnetic Diagnostics





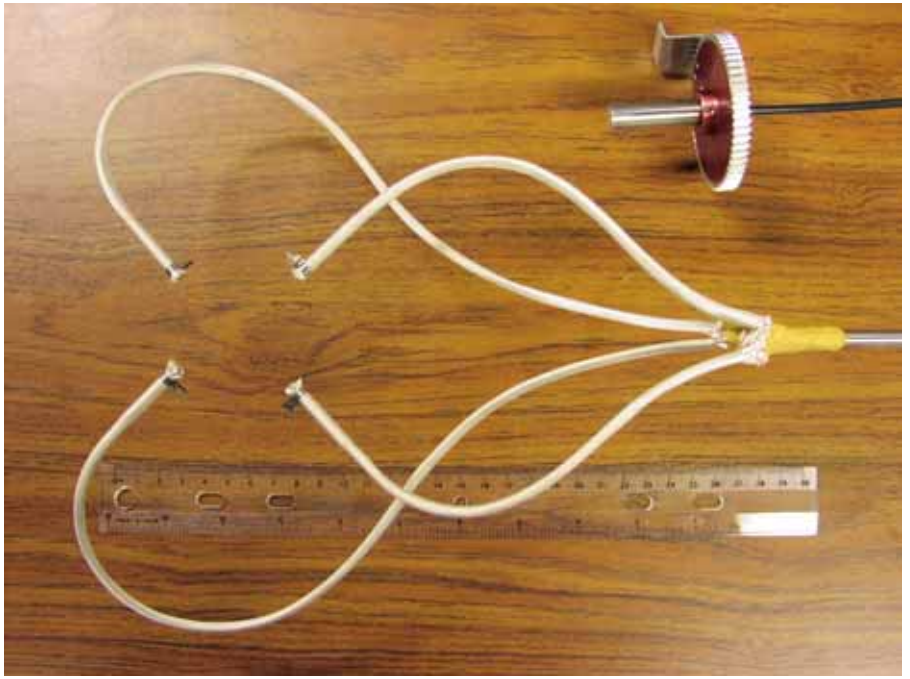

- **Excellent 2D magnetics available from the first shot.**
- **Developing systems for toroidal mode number evaluation.**

# Advanced Optical Measurements Exist

- $T_i$ and $V_i$ from Doppler spectroscopy
- Spatial resolution: 4cm x 4cm
- ~10 μs resolution
- 1m spectrometer with 512x512 CCD for dispersing and measuring light

…additionally…

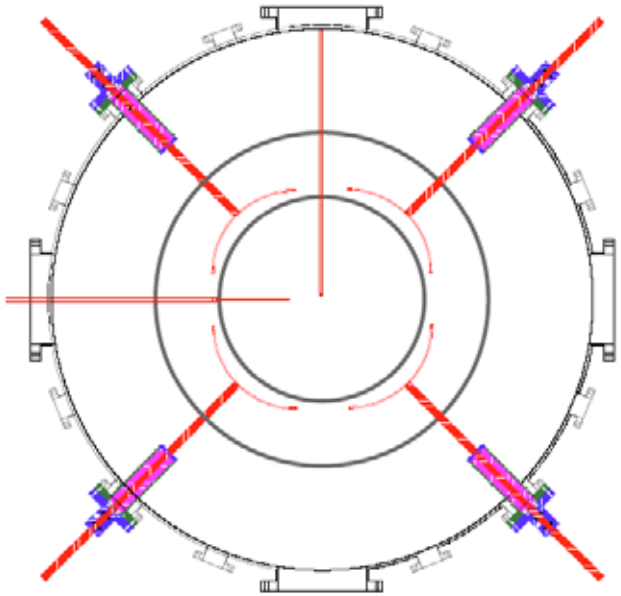
- Fast framing camera used to observing plasma shape and motion.

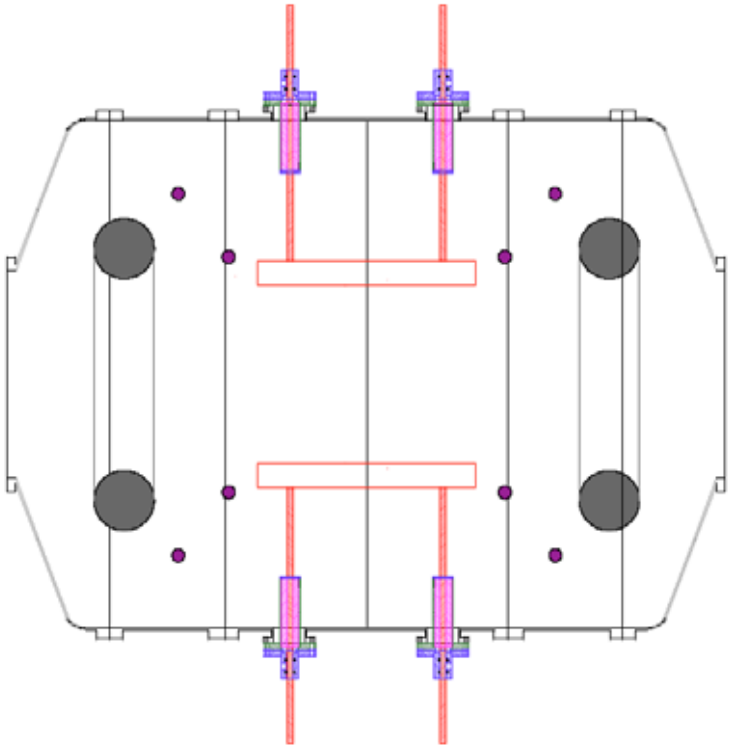


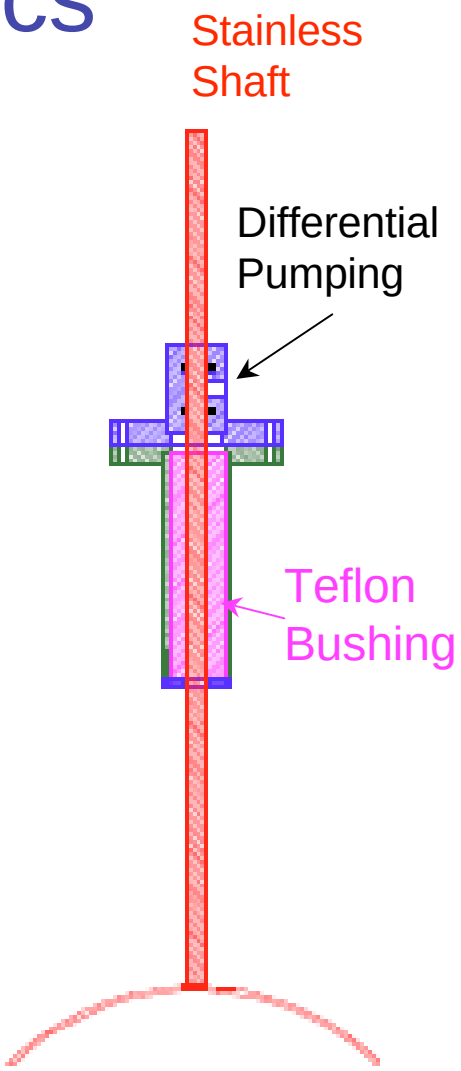
- Also Use Line-Integrated Collection Optics for nonperturbative measurements

# Preliminary Shell Structure Design Compatible With Diagnostics

- Segmented Copper shell structure allows flexibility
- Thickness >3mm provides sufficient skin time.
- Holes in shell as necessary to accommodate diagnostics
- Replaceable Shells on Movable Supports.



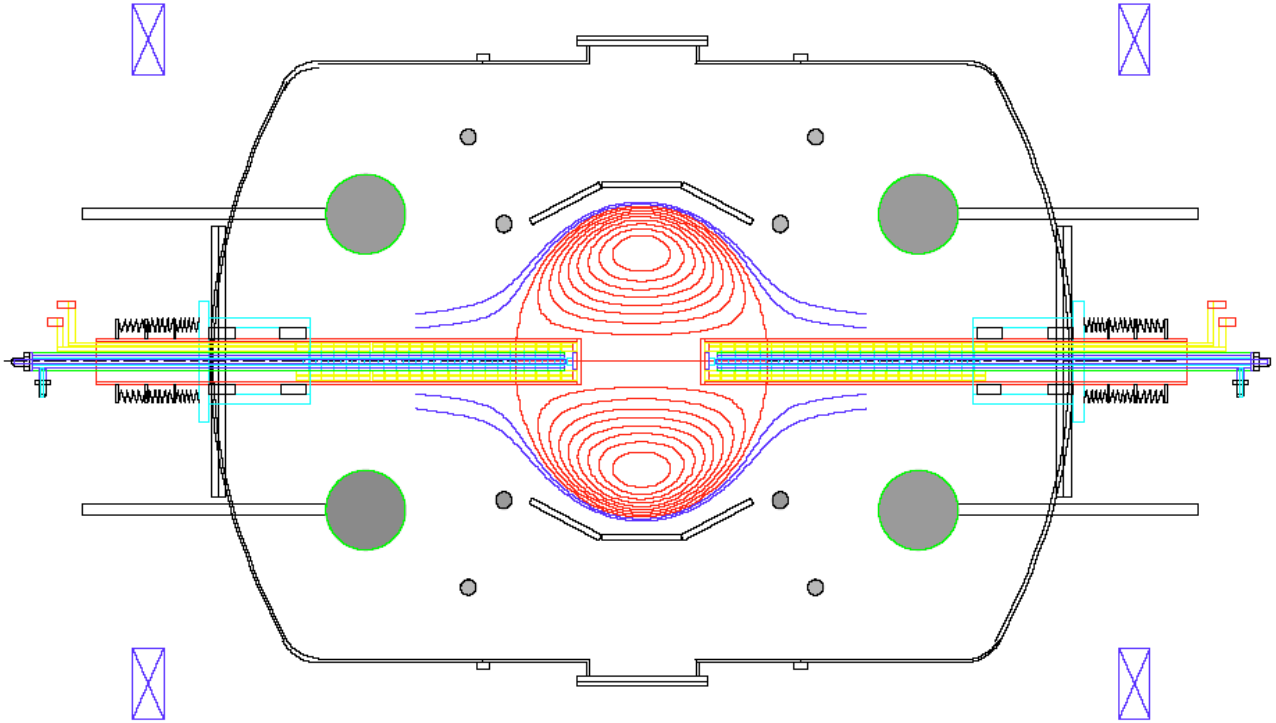






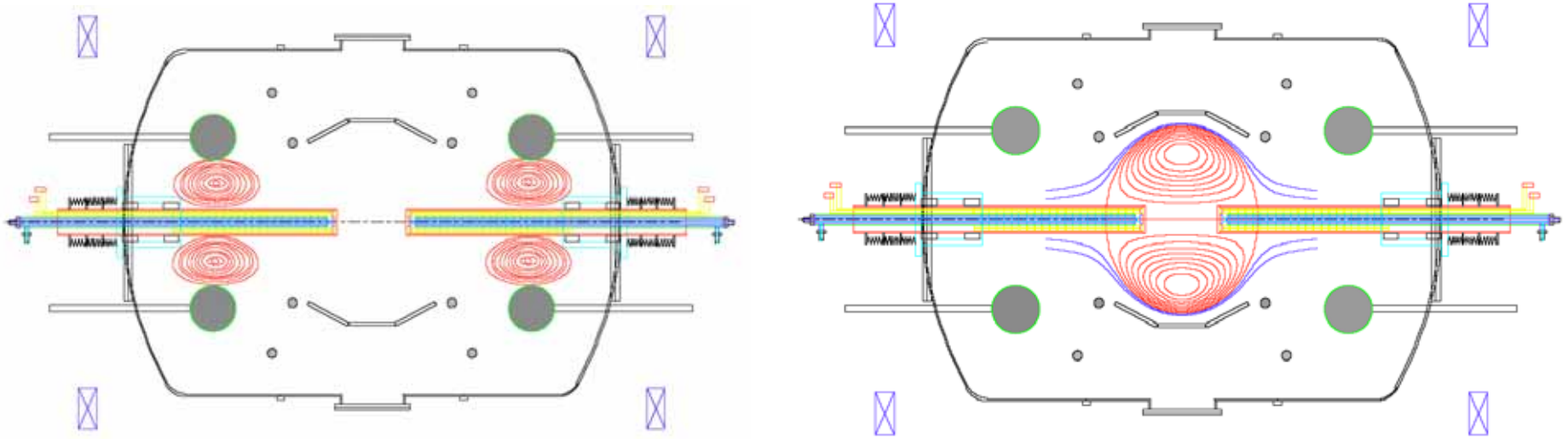

*MRX-FRC*

# Stage 2: Amplification and Sustainment using Current Transformers



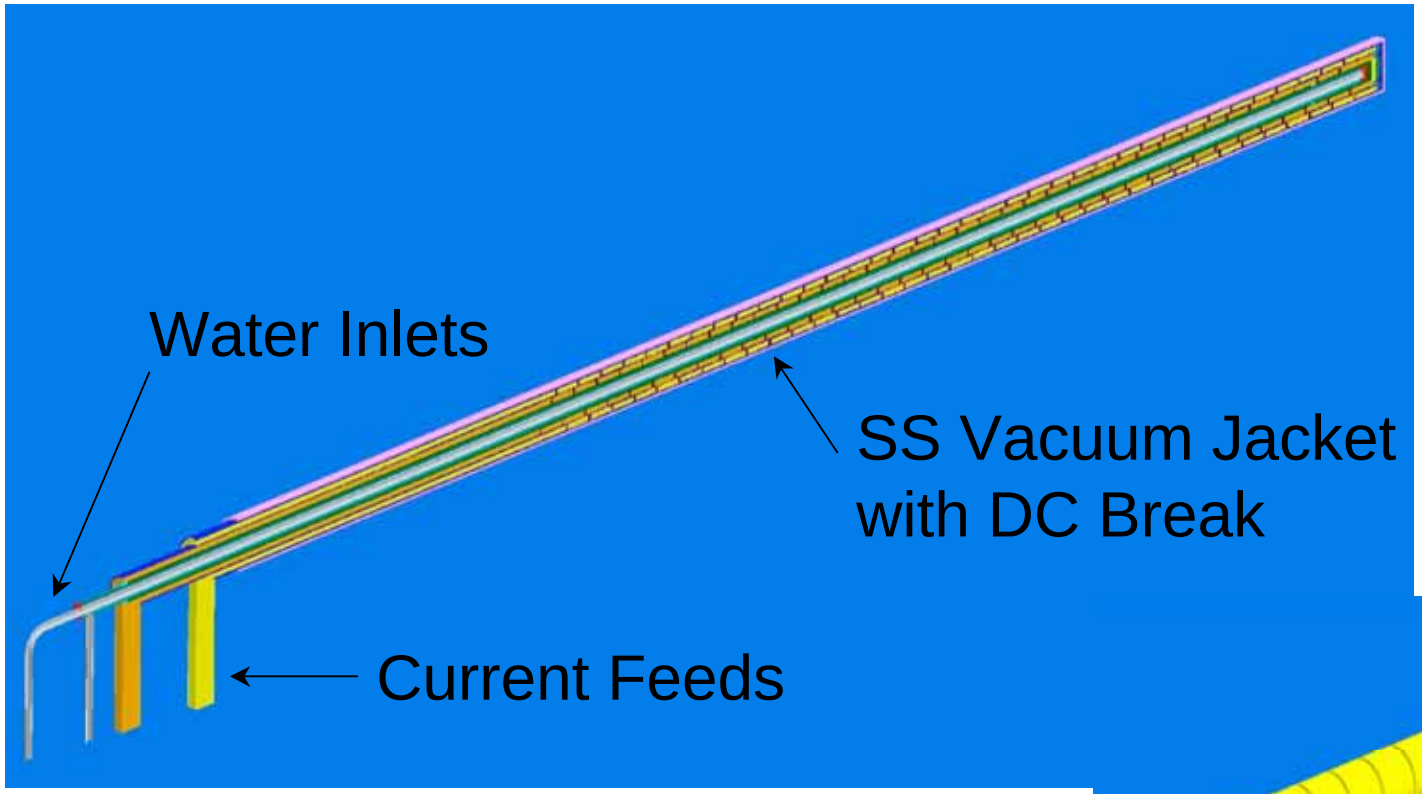
Used to Make an Attractive NBI Target Plasma

# Next Step in Design Includes Addition of Current Transformers

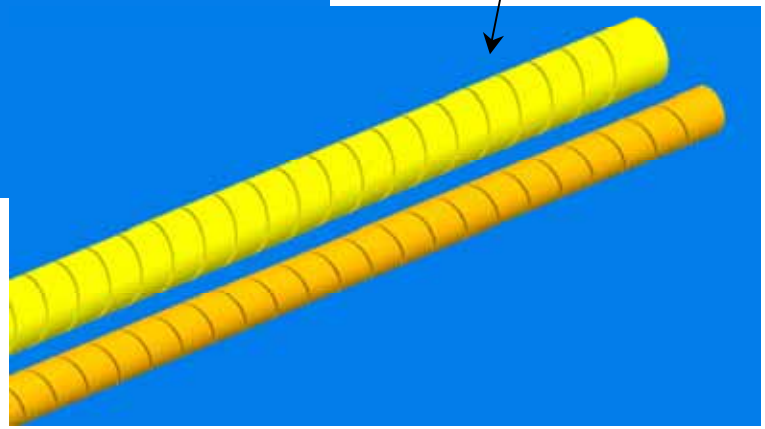


- Total flux of 51mWb, allowing $V_{loop}$=50V for 1msec
- Ends of solenoids can touch or be separated
- Can ramp up flux in the spheromak or the FRC
- Allows preservation of simply-connected geometry.
- Decoupling Transformer between Ohmic/PF and Ohmic/SF

# Preliminary Design of Transformer has been Finished



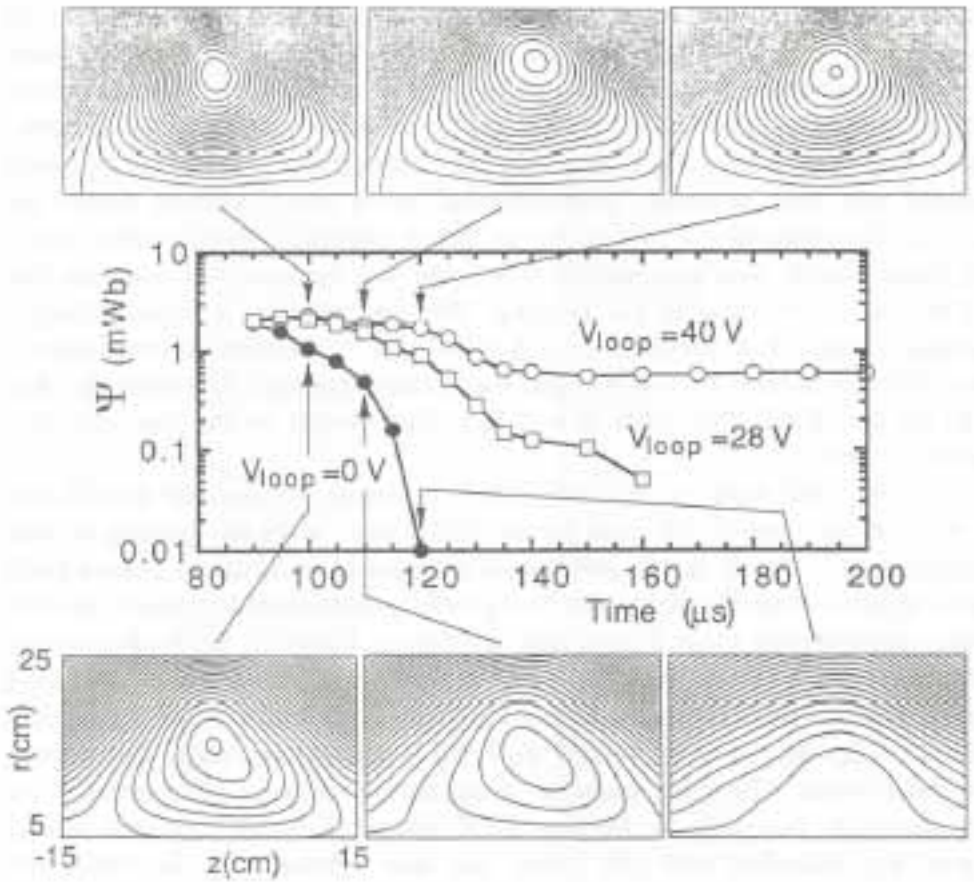

Transformer Winding From Helically Cut Copper Pipe



- 20 Turns per layer, 2 layers per transformer.
- Inductance of .012 mH, 12.7 Tesla Field
- ~6cm radius

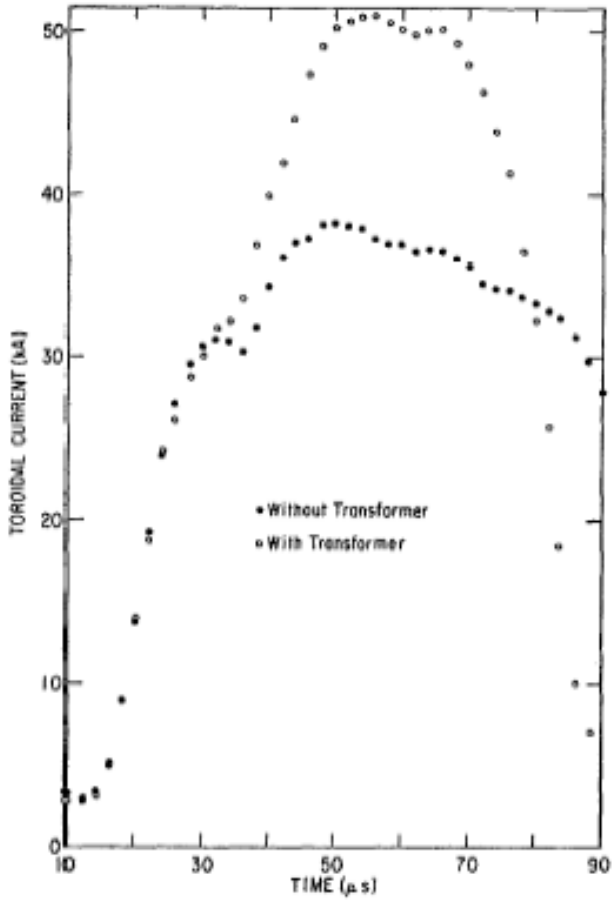
# Transformers Have Driven Current in FRCs and Spheromaks

Y. Ono, et al., IAEA-CN-56/C-4-4



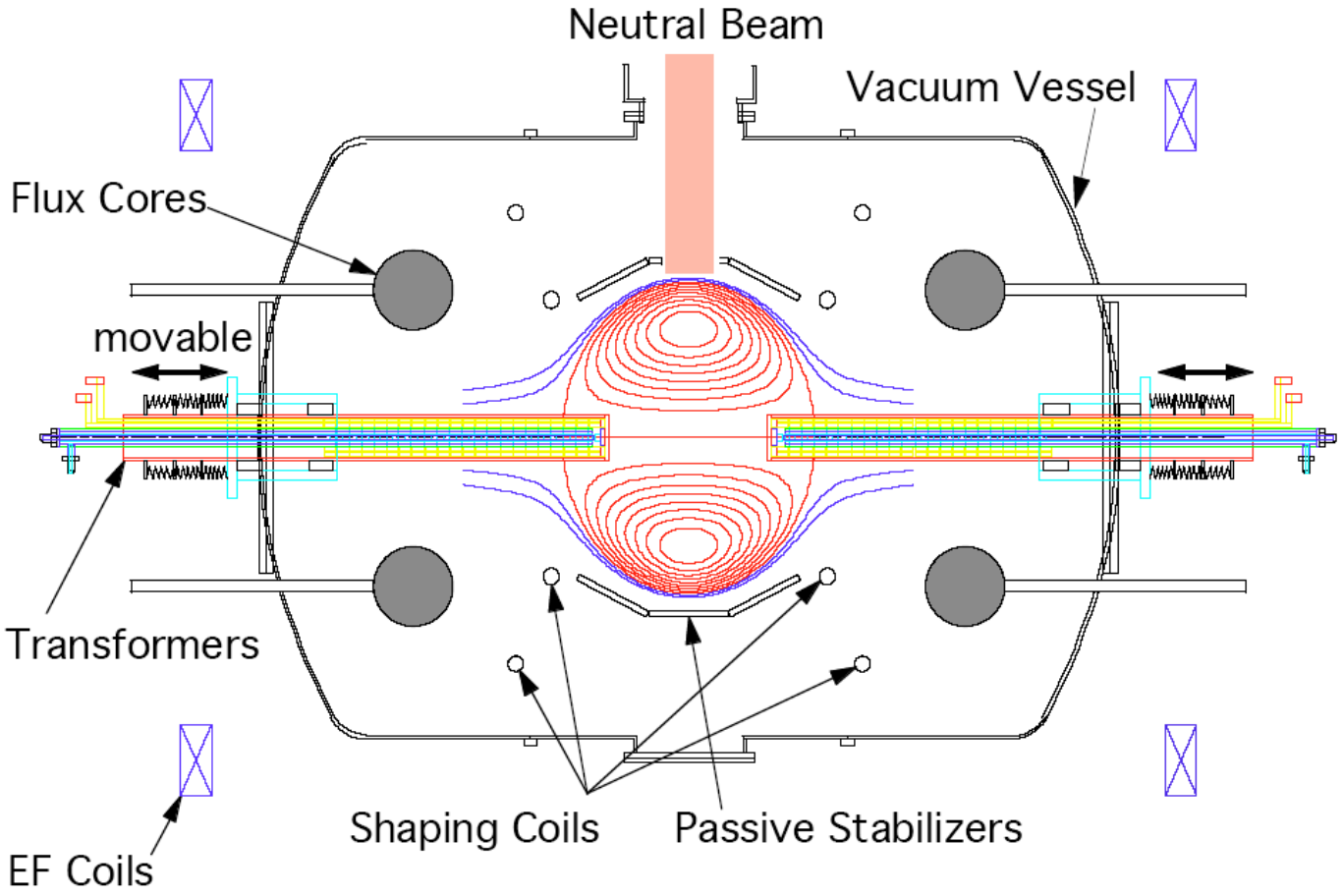

TS-3 FRC

P.E. Young, et al., Phys. Fluids B **3**, 2591 (1991)



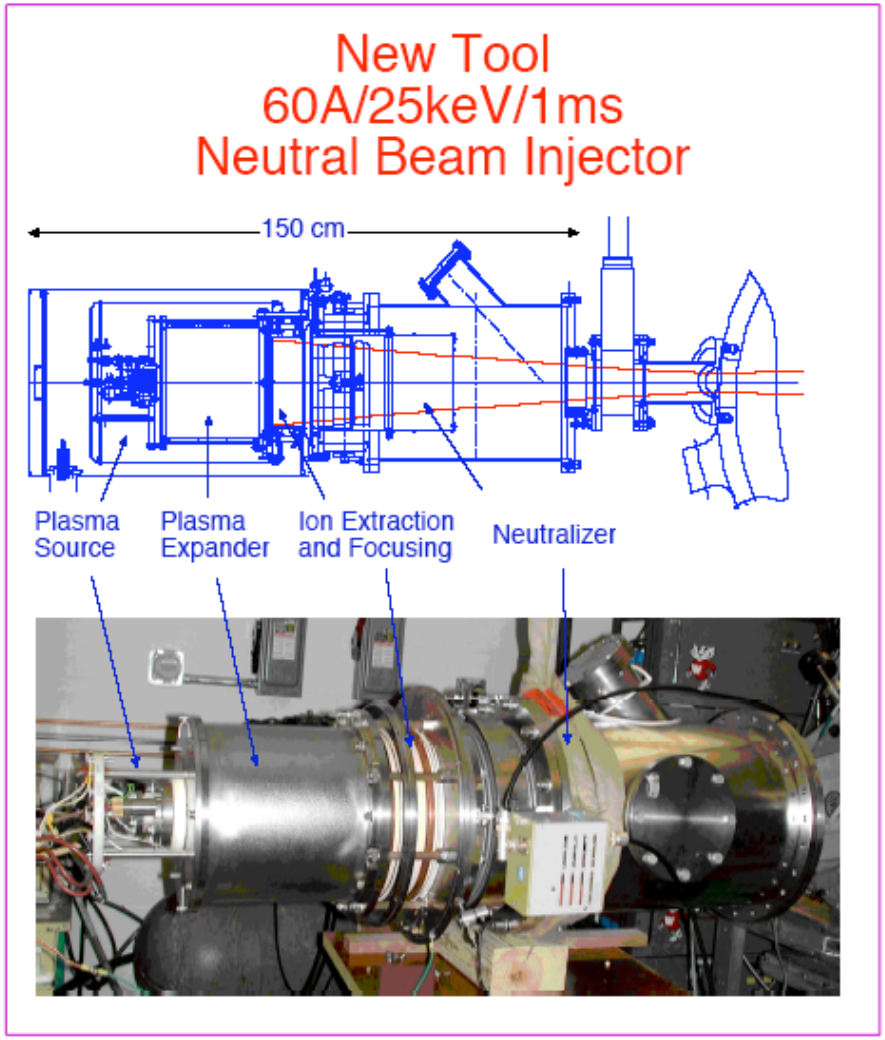

Flux Core Spheromak Proto S-1

# Stage 3: FRC Stability Studies with NBI



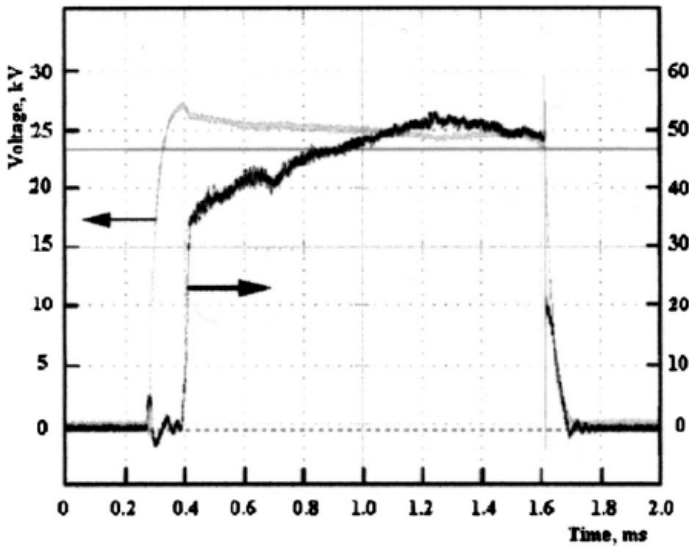
# Compact Neutral Beam Makes NBI Possible

| | |
|---|---|
| Beam Energy | 20-25keV |
| Energy stability | <5% |
| Beam Power | Up to 1.5MW for H |
| Beam Size | 4.5” D |
| Beam Composition | <10% of Molecular Ions |
| Current stability | <10% |
| Pulse duration | >1ms |
| Repetition | 1 pulse every 2 minutes |
| Distance from plasma center | 1.8 m |



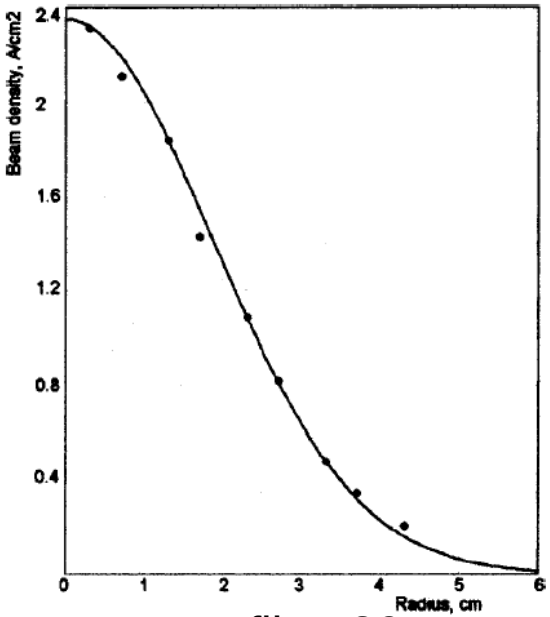
# Similar Beams Developed for the Gas Dynamic Trap and Madison Symmetric Torus

Systems for GDT Tested to Full Power



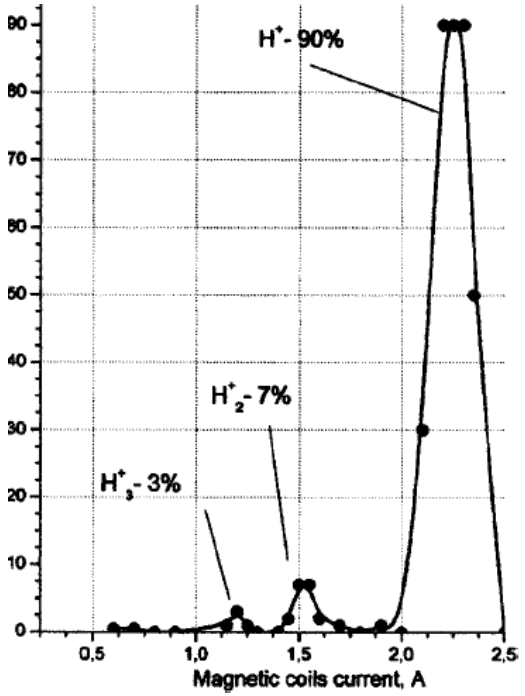

P.P. Deichuli, el, al, RSI **75**, 1816

Ion Optics Lead to Tight Focusing



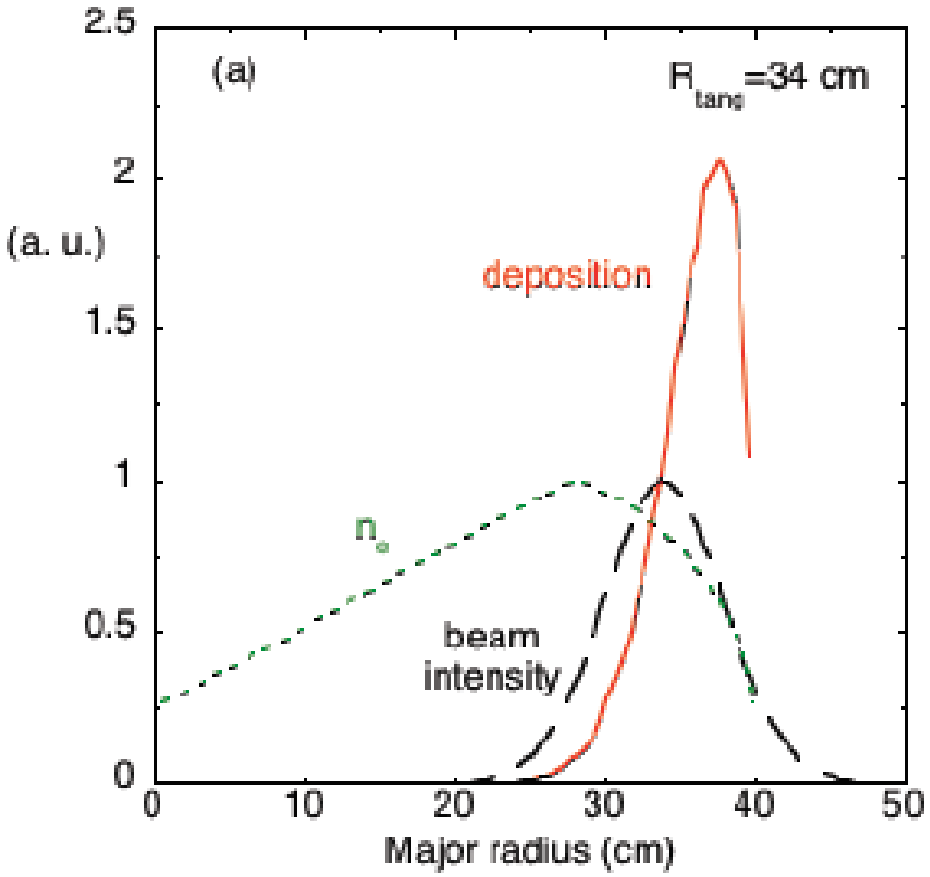

Beam Profile 120 cm from IOS

Protons Dominate the Extracted Ion Current



# Desired Target Plasmas For NBI

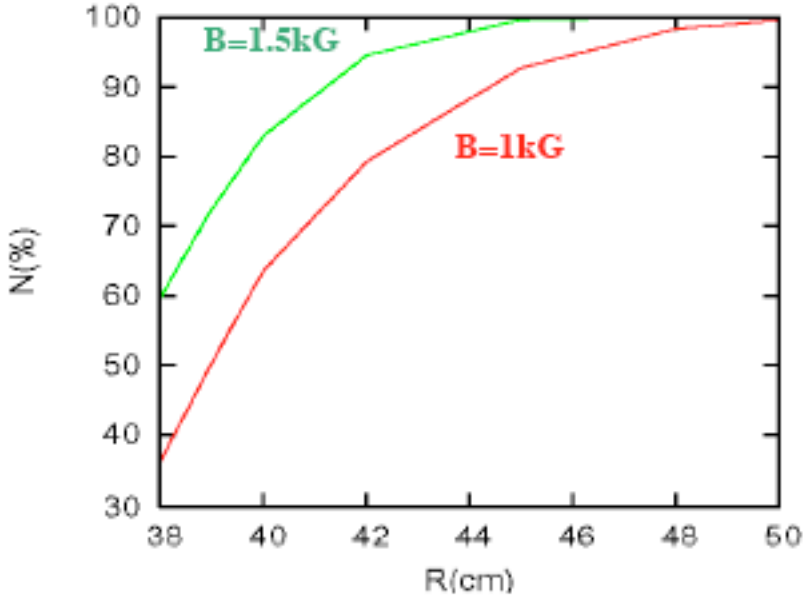
| Parameter | Value |
|---|---|
| Plasma Current (kA) | 180 |
| $B_{max}$ (kG) | 1.5 |
| Density ($cm^{-3}$) | $1x10^{14}$ |
| $T_e$ (eV) | 50 |
| $T_i$ (eV) | 600 |
| $R_p$ (cm) | 30 |
| $R_{sep}$ (cm) | 40 |
| S* | 18 |
| Trapped Flux (mWb) | 22 |



# Target Plasmas Have Sufficient Confinement of NBI

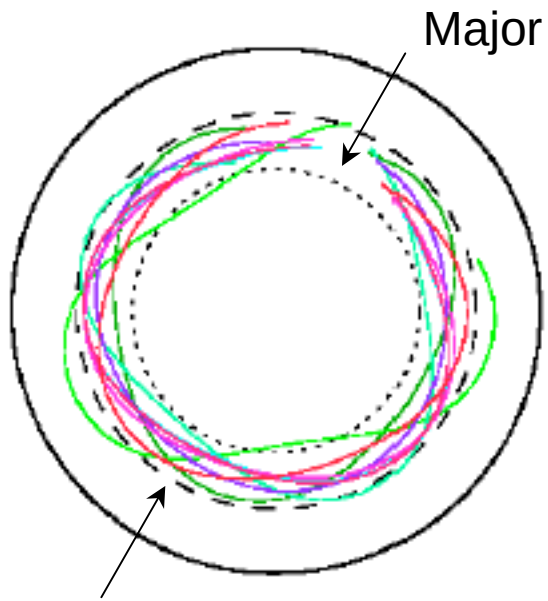
$R_{tang}$=34 cm & $E_{beam}$=25 keV

Percentage of Particles Confined




Radius of the Conducting Shell

Typical Orbits for B=1kG



# Extensive Measurements Are Planned For These Experiments

| Need | Tool | Status |
|---|---|---|
| Internal Magnetics | ~200 Channels of Internal Magnetics, 1D & 2D arrays | In Use |
| Ion Temperature and Plasma Flows | CCD/Spectrometer with Optical Probe for local Measurements | In Use |
| Electron Density and Temperature | Triple Probe | In Use |
| Plasma Motion | Fast Framing Camera | Used when Available |
| Plasma Current and Flux | Rogowski Coils and Loops | Waiting for Installation |
| Plasma Density | Single Chord Interferometer | In Design |
| Instabilities | Toroidal Pick-Up Coils Arrays | In Design |
| Neutral Density | H-alpha Detector Systems | In Design |
| Fast Ion Confinement | Neutral Particle Analyzer | Scoping Studies |
| Instabilities | SXR arrays | Scoping Studies |
| Electron Temperature | Thomson Scattering | Scoping Studies |

# Summary

- Preliminary design for MRX-FRC is complete, based on existing MRX facility.
- Staged approach has been developed:
  - Spheromak merging a conducting shell stabilization
  - Current amplification and sustainment (~20mWb)
  - High power NBI for sustainment and stability studies

- Program awaits DOE approval and funding.

# Proposed Schedule for MRX-FRC

- SF power supply is to be commissioned by Dec.
- Upgrade of EF rectifier upgrade (5000A yielding ~.5kG on axis) to be completed by Dec.
- Shaping coils are under construction.
- Conducting shell structures are under design.
- Construction of CTs and Ohmic power supply to begin in 1st year after approval
- NBI scoping in second year and installation during third…Two options for system
  - Purchase new from Russia.
  - Temporary test with system from Madison Symmetric Torus

# The End

# Initial Formation Scheme will Allow Merging and Current Sheet Experiments

- Single set of shaping coils causes X-point configuration.
- Strong EF pushed the spheromaks in as they pull together.
- Compatible with current sheet experiments

# Future Scheme Adds Extra Shaping Coils for Flexibility and Additional EF

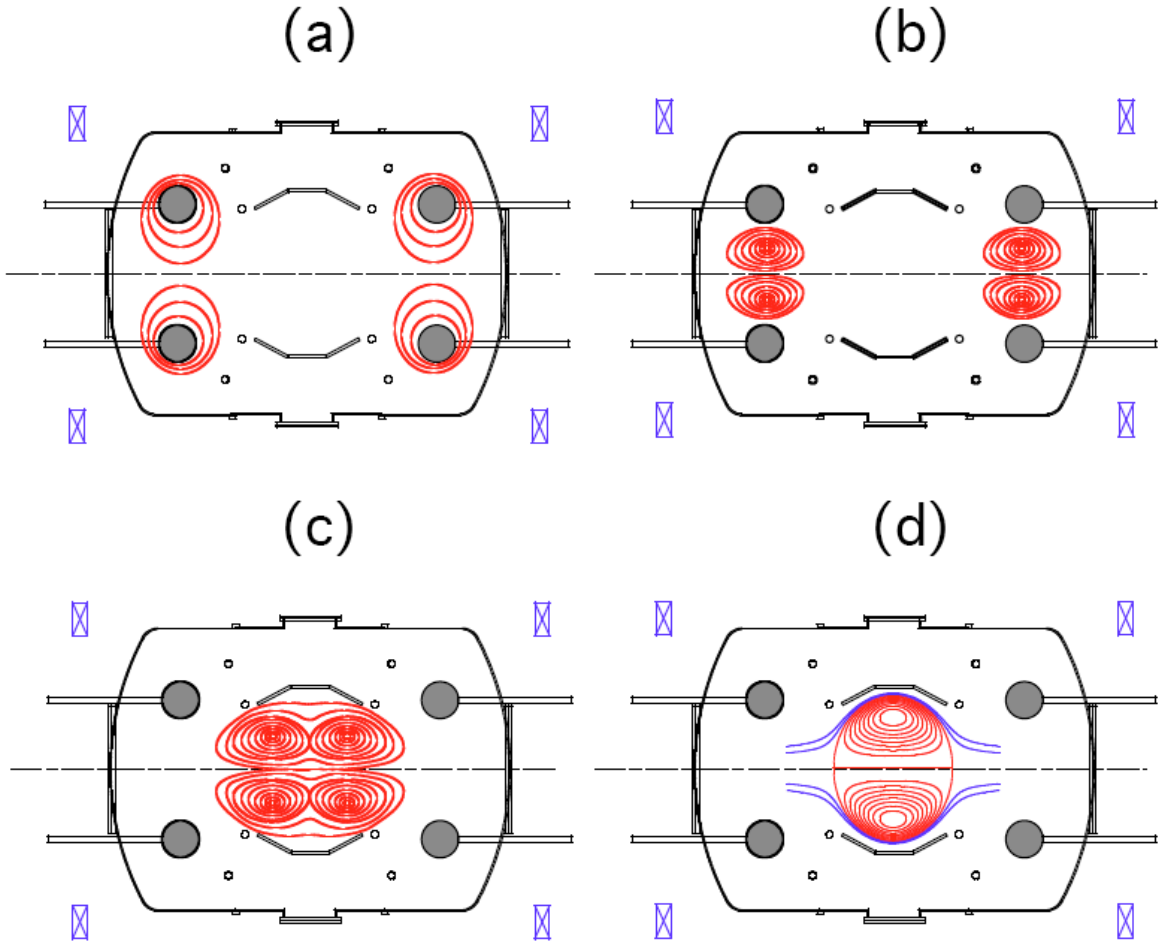
# FRC Formed By Counter-Helicity Spheromak Merging

(a) Plasma Formation

(b) Spheromak Pinch-Off

(c) Spheromak Merging

(d) Final FRC State



# Current Focus of Experiment Has Been Reconnection and Current Sheets

- Establishment of a generalized Sweet-Parker Model
- Establishment of anamalously large resistivity in the low collisionality regime.
- Measurement of Magnetic fluctuations correlated with enhanced resistivity