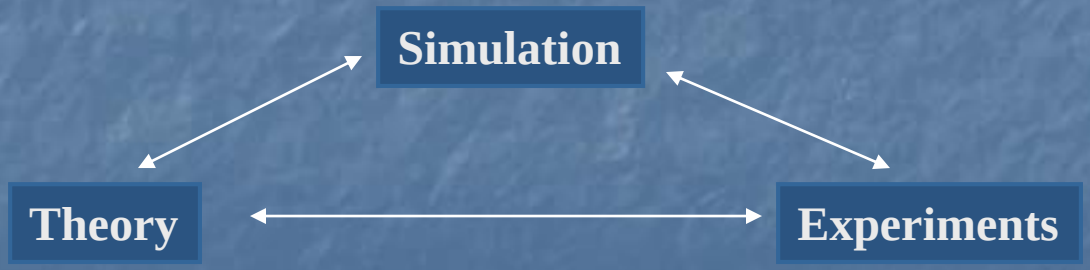
Research at UHCL

- Current Application Focus
  - MHD Augmented Propulsion (UHCL)
  - RF Magnetized Plasma Sources, Atmospheric Plasma Torches (Propulsion, Re-entry plasma) (UHCL/JSC)
  - Plasma Actuator/Airfoil for Hypersonic Flight (UHCL)
  - FRC-based Electric Propulsion (Fusion/Propulsion)
  - Lightning Stroke Simulation (JSC)
  - Magnetic Reconnection (UHCL)

- Some applications require neutrals:
  - Development 0-D Plasma-Neutral model

Simulation Studies

1. *Fluid (MHD) Plasma Simulation*
2. *Particle Simulation*
3. *Computer Science: Massively Parallel Processing*



MHD Plasma Simulation

1. **Pre-Maxwell Equations:** $\mathbf{j}_p \Rightarrow \mathbf{E}\ , \mathbf{B}_p$

2. **Continuity Equation:** $n, \mathbf{u} \Rightarrow \dfrac{\partial n}{\partial t}$

3. **Momentum Equation** $\mathbf{j}, \mathbf{B}, \nabla p\ , \nu, \rho, \mathbf{u}, \nabla \mathbf{u} \Rightarrow \dfrac{\partial \mathbf{u}}{\partial t}$

4. **Energy Equation** $n, \nabla T, p, \mathbf{u}, \mathbf{q}, Q \Rightarrow \dfrac{\partial T}{\partial t}$

5. **Ohm's Law (resistive MHD)** $\mathbf{u}, \mathbf{B}, \eta, \mathbf{j}_\mathbf{p} \Rightarrow \mathbf{E}$

MHD Plasma Simulation

1. **Pre-Maxwell Equations:** $\dfrac{\partial \mathbf{B}_p}{\partial t} = -\nabla \times \mathbf{E}\ , \qquad \nabla \times \mathbf{B}_p = \mu_0 \mathbf{j}_p$

2. **Continuity Equation:** $\dfrac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{u}) = 0$

3. **Momentum Equation:** $\rho\left(\dfrac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}\right) = \mathbf{j} \times \mathbf{B} - \nabla p - \nabla \cdot (\nu \rho \nabla \mathbf{u})$

4. **Energy Equation:** $\dfrac{n}{\gamma - 1}\left(\dfrac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = p \nabla \cdot \mathbf{u} - \nabla \cdot \mathbf{q} + Q$

5. **Ohm's Law (resistive MHD):** $\mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta \mathbf{j}_\mathbf{p}, \mathbf{B} = \mathbf{B}_0 + \mathbf{B}_p$

MHD Plasma Simulation

Physical Model:

Legenda

$\nu = m_e/m_i$ is the mass ratio

μ_0 and ε_0 are the permeability and permittivity of free space

n is the number density

ρ is the mass density

v is the center of mass velocity

B is the magnetic flux density

E is the electric field

J is the current density

p is the scalar pressure

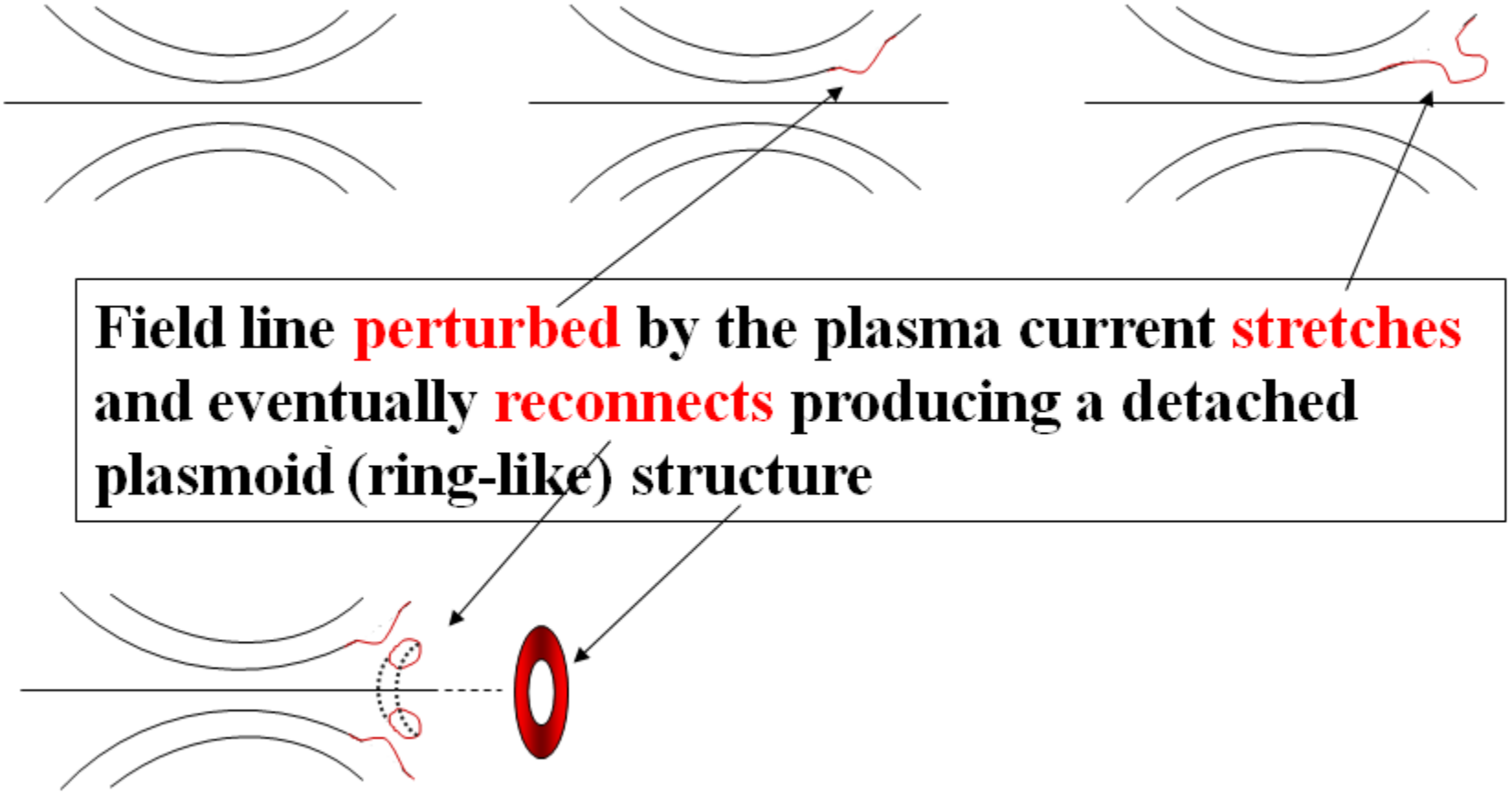
Q is the heat flux

η is the electrical resistivity

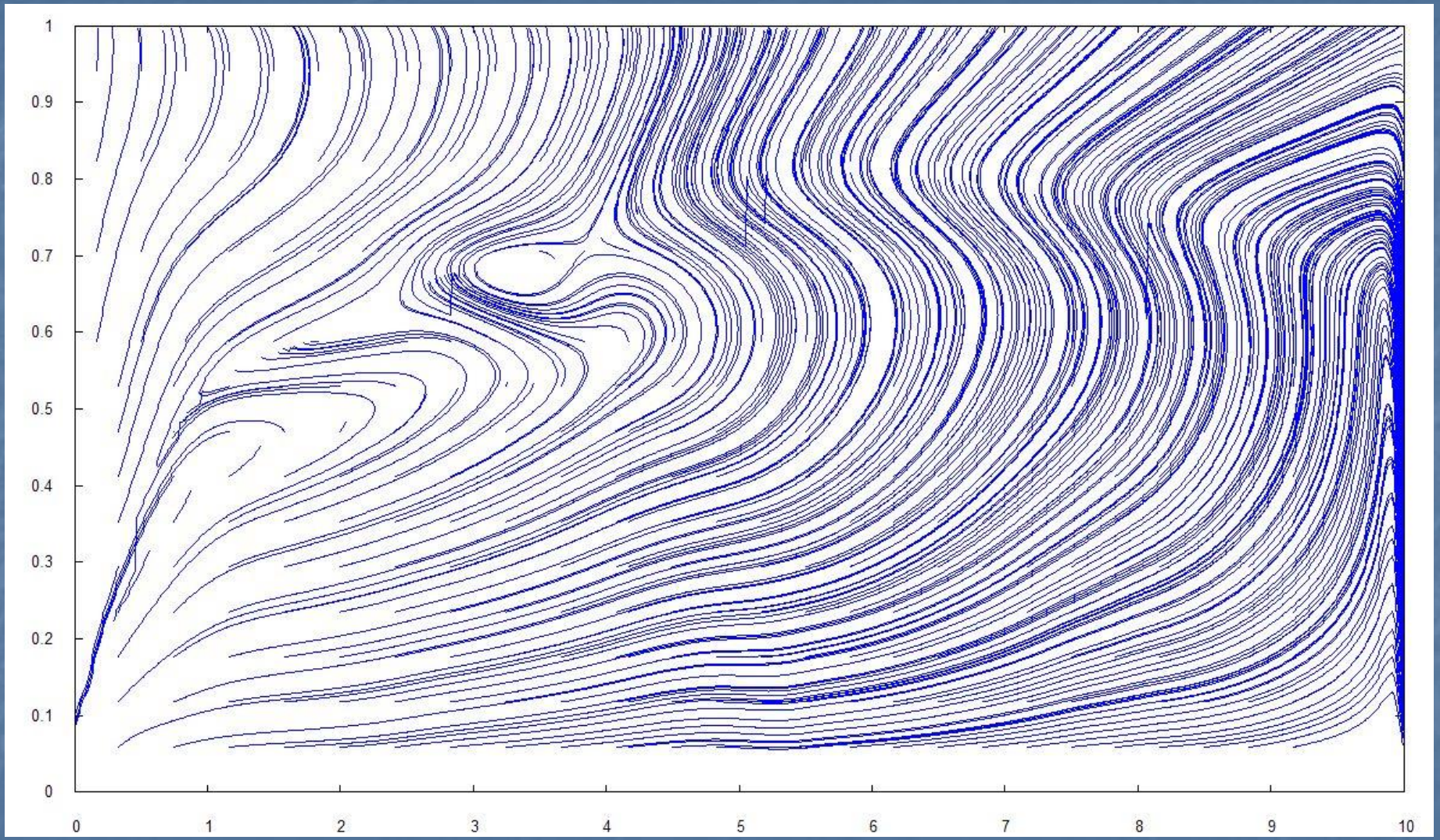
$\mathbf{P'} = p\mathbf{I} + \Pi$, **I** is the unit tensor

Π is the symmetric, traceless part of the stress tensor

Magnetic Reconnection Leading to Detachment



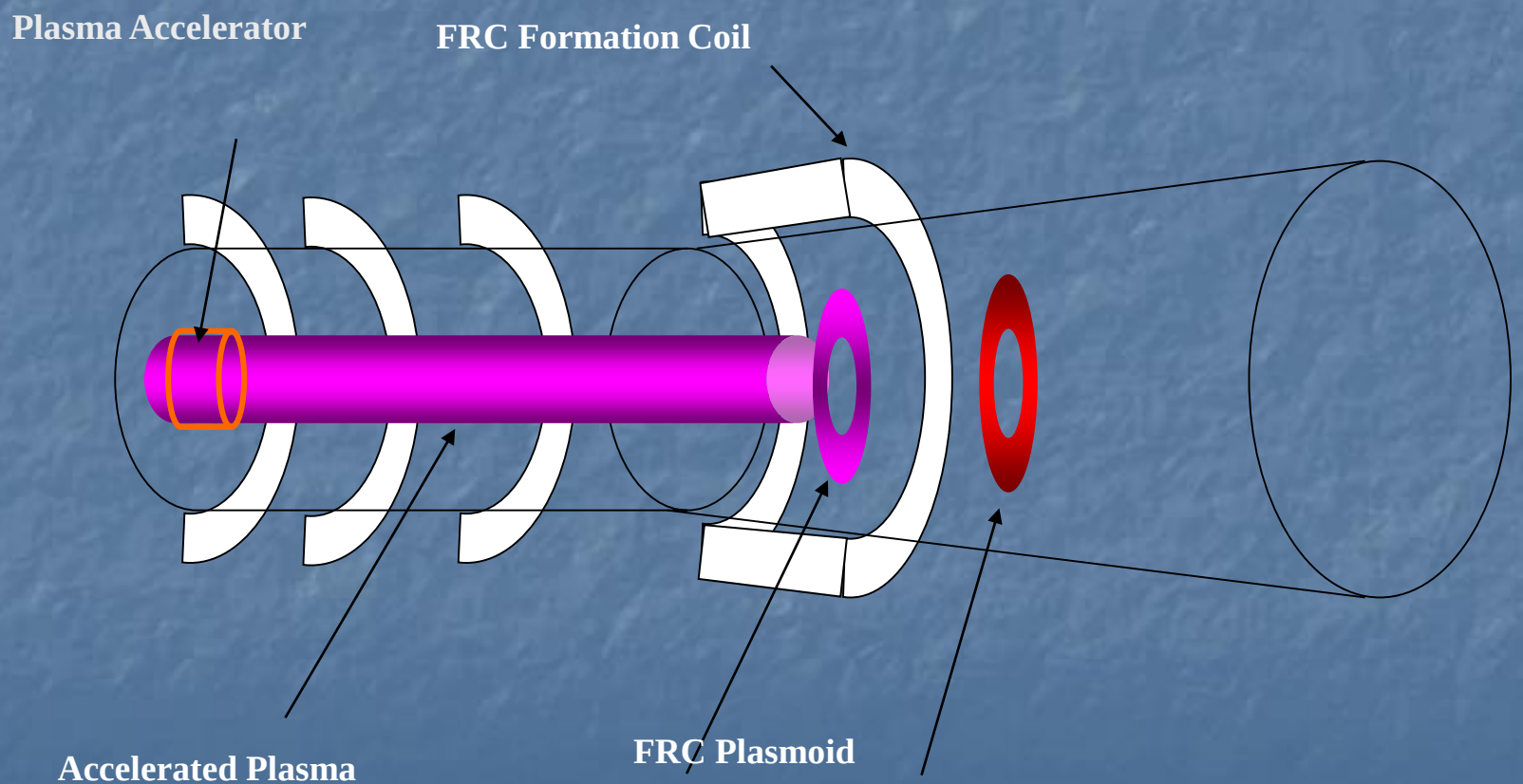
Reconnection Studies: Magnetic Nozzle Perturbation



NIMROD MHD Simulation: Step 450000 = 425 μs

FRC-based Plasma Thruster

- The plasma detachment in the nozzle is induced in a controlled way, through the formation of a sequence of FRC plasmoids.



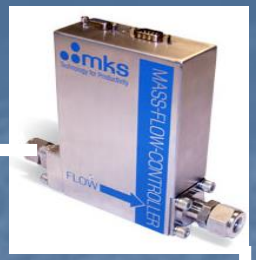
Simulation Hardware

- “Columbia” at NASA-Ames: 20 SGI® Altix™ 3700 superclusters, each with 512 Itaniunm processors = 10240 processors

- In-house Linux Clusters

Building the UHCL Plasma Lab

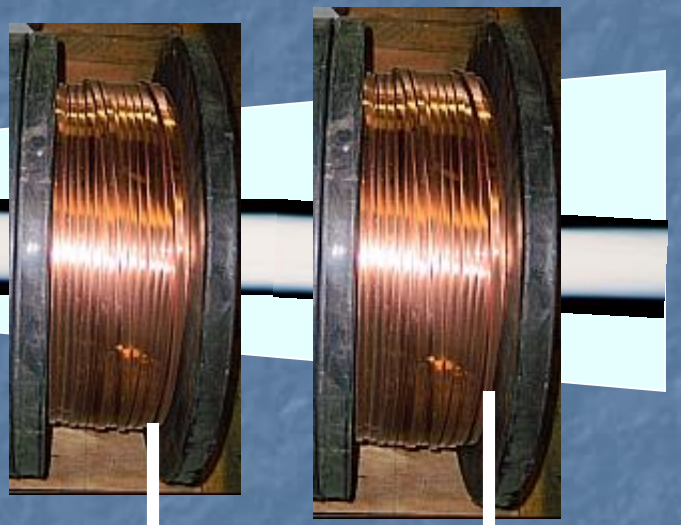
Argon



Mass Flow Controller

RF Plasma Torch

Magnetic Nozzle Coils



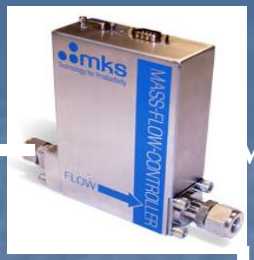
Automatic RF
Matching Networks

RF Generator

Coil Power Supply

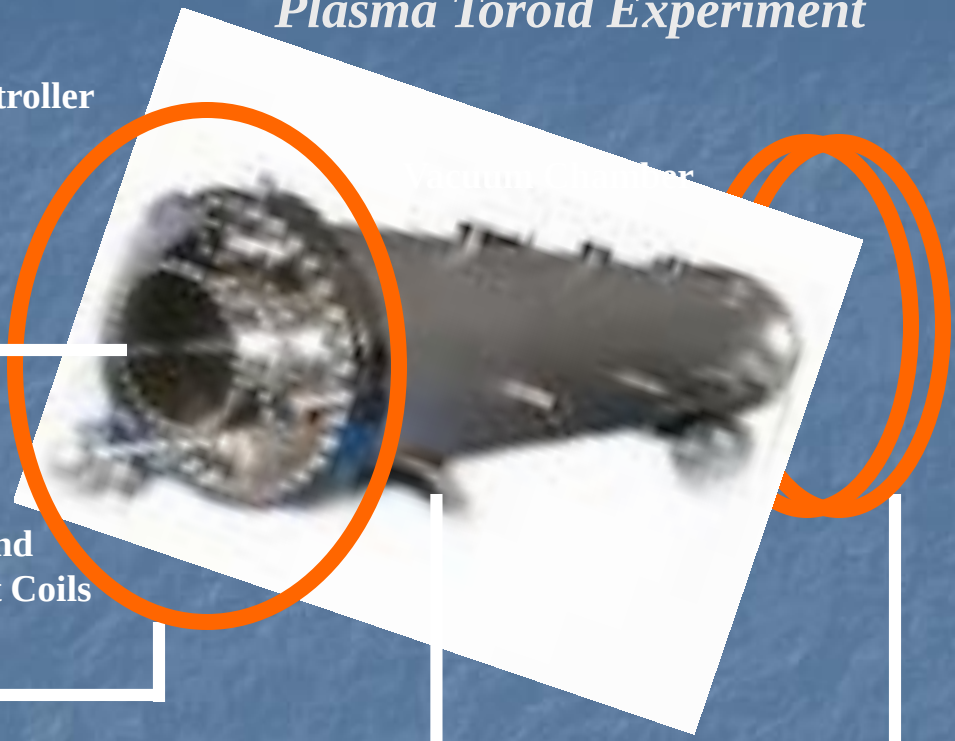
Building the UHCL Plasma Lab

Argon



Mass Flow Controller

Plasma Toroid Experiment



Formation and
Confinement Coils

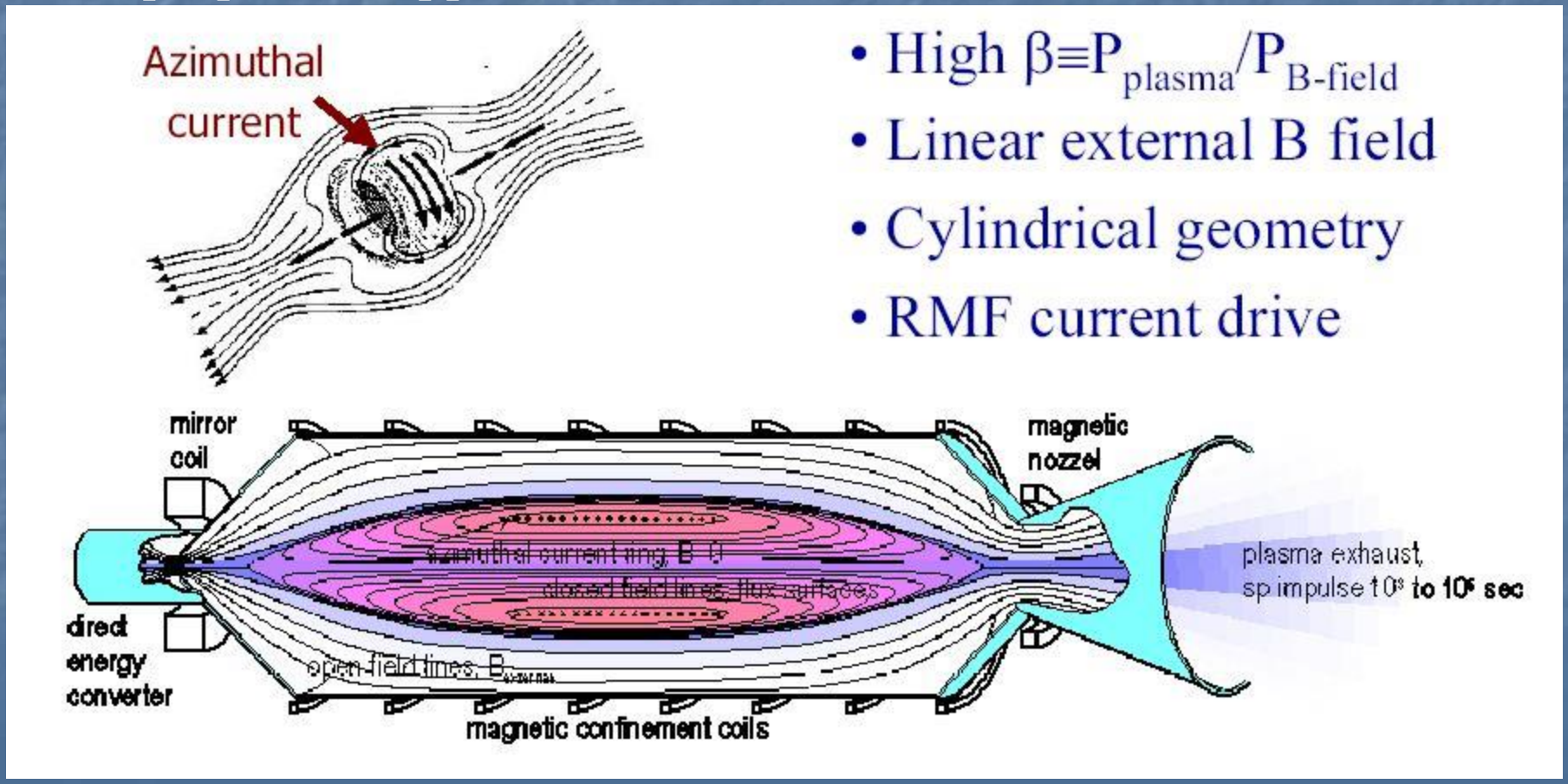
High-Voltage Power
Supply and Capacitor Bank

High-Vacuum Pump

Coil Power Supply

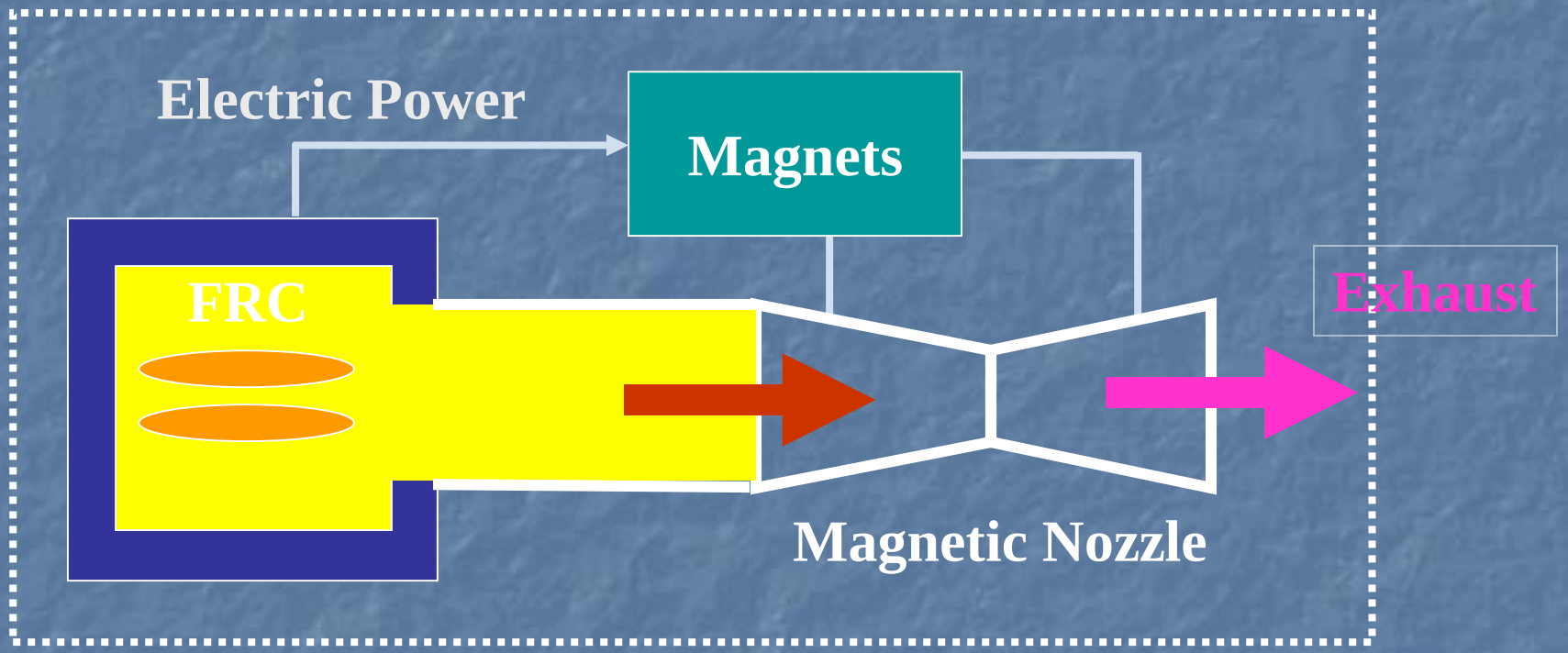
Fusion and Plasma Propulsion

The **Field Reversed Configuration** (FRC) is a well studied plasma confinement scheme that is very appealing also for propulsion applications



A conceptual scheme for a FRC Rocket

Fusion and Plasma Propulsion



*Plasma and power production scheme for a **FRC** fusion (still to be demonstrated…) **direct** propulsion rocket*

FRC Plasmoid Fusion-Propulsion Concept

A sequence of FRC plasmoids is formed from an accelerated plasma column