The Helimak Experiment

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THE UNIVERSITY OF TEXAS AT AUSTIN

Helimak

The Helimak is a major international experiment for the study and control of plasma turbulence

- Devised by Stan Luckhardt at UCSD
- Managed and operated by the University of Texas
- Engineered and fabricated by the Institute of Plasma Physics of the Chinese Academy of Sciences with the Shanghai Boiler Works, PRC
- Installed at the University of Texas Fusion Research Center

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Motivation

- Physics: Plasmas are further from thermodynamic equilibrium than any other laboratory system; plasmas are a unique challenge to our understanding of non-equilibrium systems

- Fusion Power: Transport -- the processes by which plasmas lose heat and relax to thermodynamic equilibrium -- is the least-understood aspect of device physics and design.

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Background

Even the best-confined plasmas -- the best cases in tokamaks and stellarators -- lose heat and energy orders of magnitude faster than predicted by the most sophisticated fundamental calculations -- neoclassical theory.

Just as fluids far from equilibrium develop instabilities, convective cells, and turbulent eddies to enhance transport, plasmas are unstable and exhibit turbulence.

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The Idea

❖ Design an experiment with instabilities and turbulence representative of that found in fusion plasmas

❖ Make the geometry as simple as possible to facilitate comparison with theory and computer simulations

❖ Choose experimental parameters for which complete measurements of the turbulence characteristics are possible

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The Helimak

- The magnetic field lines are helical
- The plasma is symmetric around the rotation of the helix and approximately uniform along the length of the helix; the plasma varies only with the radius of the helix
- A plasma density gradient together with the curved magnetic field lines suffices to drive plasma instabilities and turbulence of the drift-wave class that is universal in fusion

Outline

- Design
- Construction
- Assembly
- Operation
- Results

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Design Concept

The genesis of the Helimak was the observation that electron cyclotron heating applied to start a tokamak discharge produced a very good plasma. The combination of toroidal and vertical magnetic field produced helical field lines. Although a simple configuration with toroidal symmetry should lack an equilibrium and be violently unstable, the field lines terminated on the top and bottom of the vacuum vessel. Since the vessel was conducting, currents could flow from top to bottom, stabilizing the plasma.

This is a Helimak. In cylindrical coordinates (r,θ,z), a strong B_θ with a weak B_z create helical field lines. The field line terminations at the ends are connected electrically. The fields are created in a toroidal vacuum vessel with a set of 16 toroidal field coils (equivalent to a current along the axis of the cyclinder) and three vertical field coils in a modified Helmholz arrangement. The vertical field is constant over the plasma volume, whereas the toroidal (azimuthal) field varies as 1/r from the axis of the cylinder.

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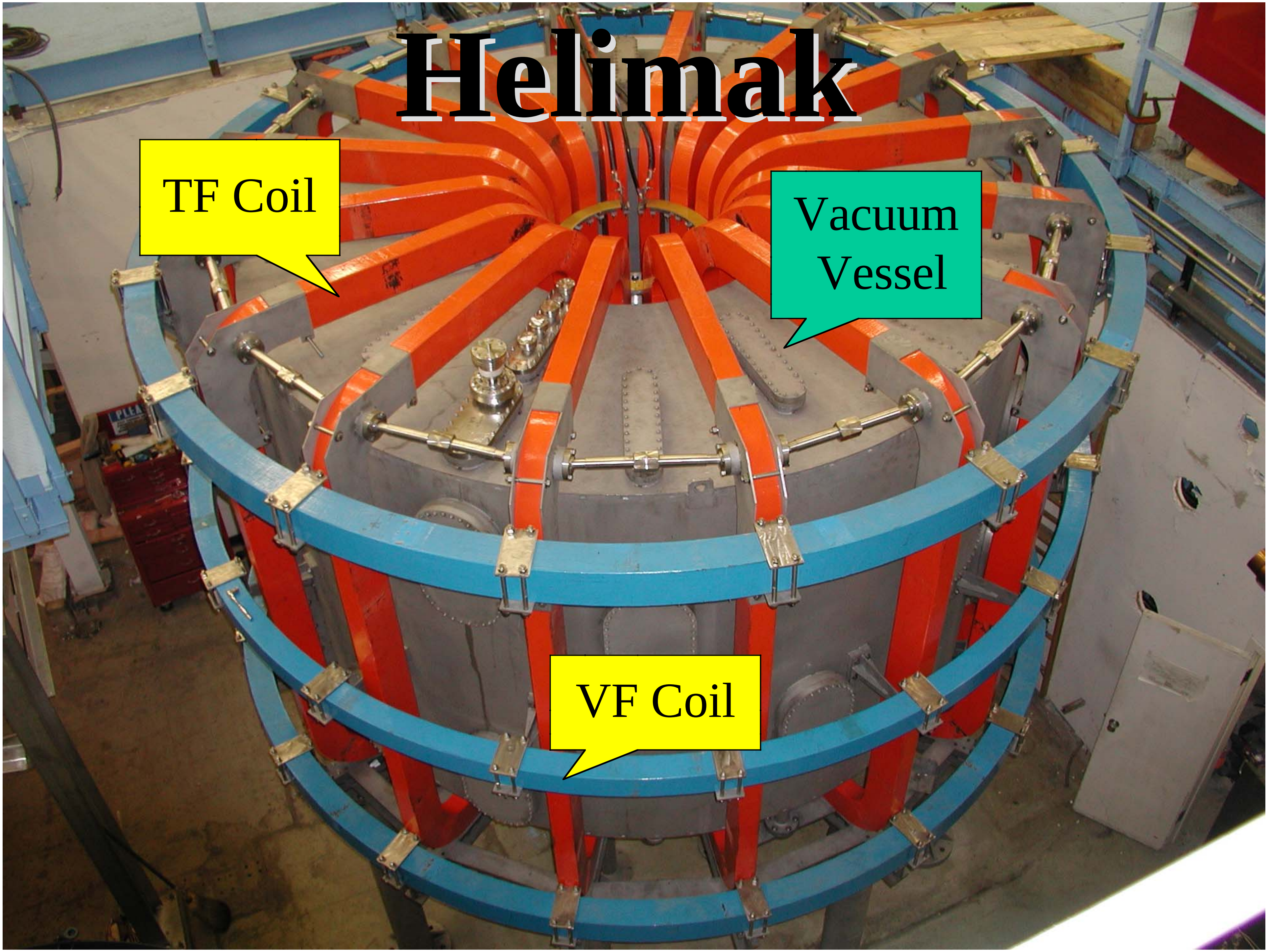
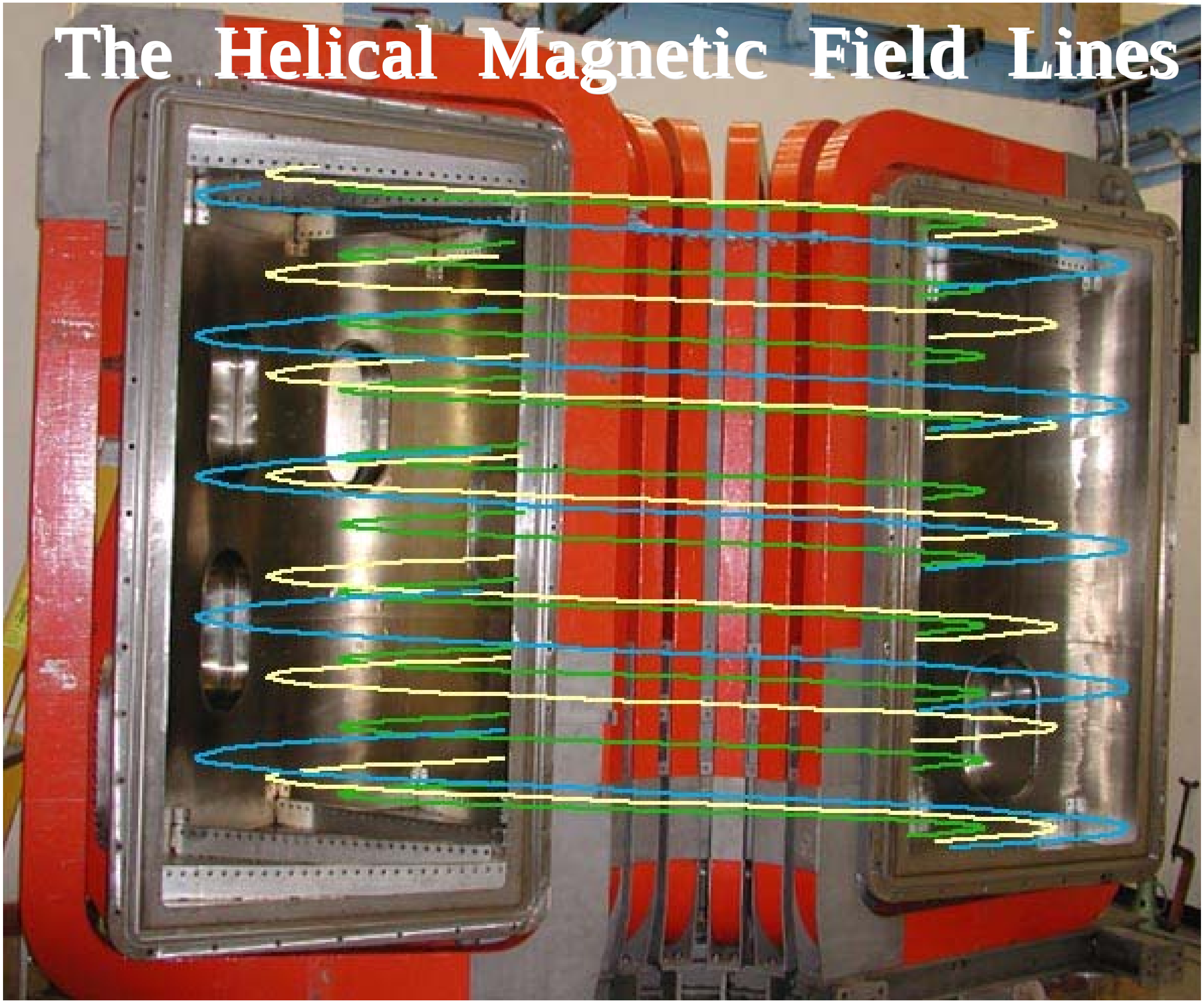


The Helical Magnetic Field Lines



Engineering Parameters

$\langle R \rangle = 1.1$ m

$0.6 \text{ m} < R < 1.6 \text{ m}$

h = 2 m

$B_T = 0.1$ T

$B_V \leq 0.01$ T

Pulse $\geq$ 60 s

Plasma Source: 8 kW ECH @ 2.45 GHz

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Plasma Parameters

$n \leq 10^{11}\ \mathrm{cm}^{-3}$

$T_e = 10$ eV

Connection length: $20\ \mathrm{m} < L < 500\ \mathrm{m}$

$c_s = 3 \times 10^4$ m/s

$V_{drift} = 100$ m/s

$V_{diamagnetic} = 10^3$ m/s

t_p (parallel loss) > 1 ms

$2\ \mathrm{kHz} < n_{drift\text{-}wave} < 20\ \mathrm{kHz}$

Flow: $0 < E_r < 10^3$ V/m

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Design Features

The Most Simple Realistic Geometry

- > Cylindrical slab -- no toroidal effects, easy comparison to theory and codes
- > One-dimensional (radial) equilibrium
- > Magnetic shear
- > Accurate model of tokamak SOL; long field lines good approximation to infinite field lines of confinement devices

Thorough Diagnostics

- > Langmuir probes and probe arrays may be used everywhere to measure all parameters
- > Spectroscopic measurements of flow

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Special Feature

Access to field lines at end plates allows control of flow shear

> Control of $E_r(r)$ -- E X B flow

> Control of $j_{||}(r)$

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Construction

From the conceptual design, the Institute of Plasma Physics of the Chinese Academy of Sciences (ASIPP) in Hefei completed the engineering design, built the magnet coils, and supervised the fabrication of the vacuum vessel and mechanical components at the Shanghai Boiler Works (SBW). The components were assembled, the vacuum vessel tested, and the parts packed for shipment at the SBW.

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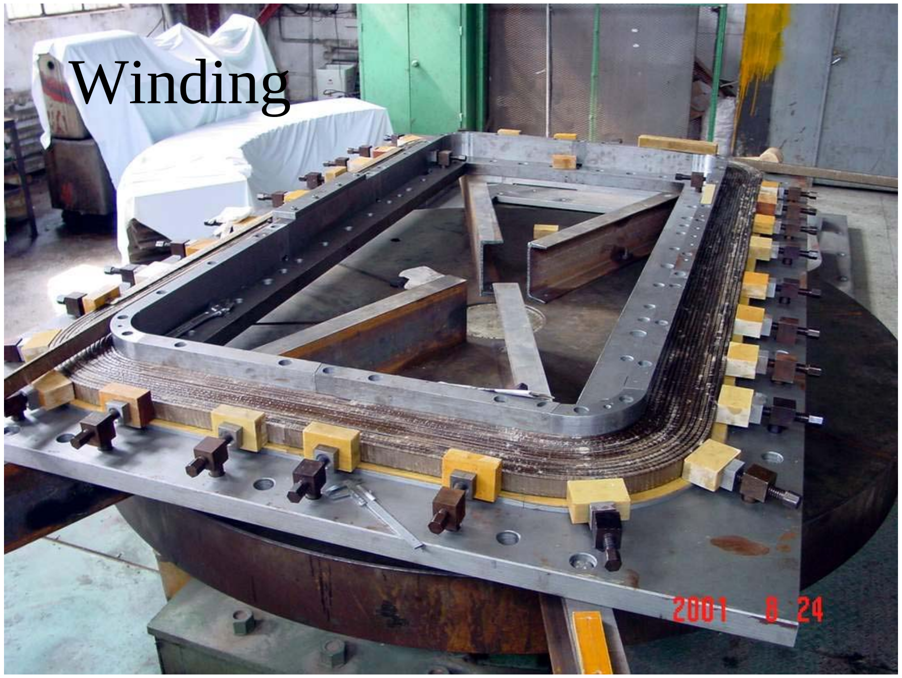
TF Coils



Oven for curing coils

Vacuum Vessel Case
at SBW
December 2001

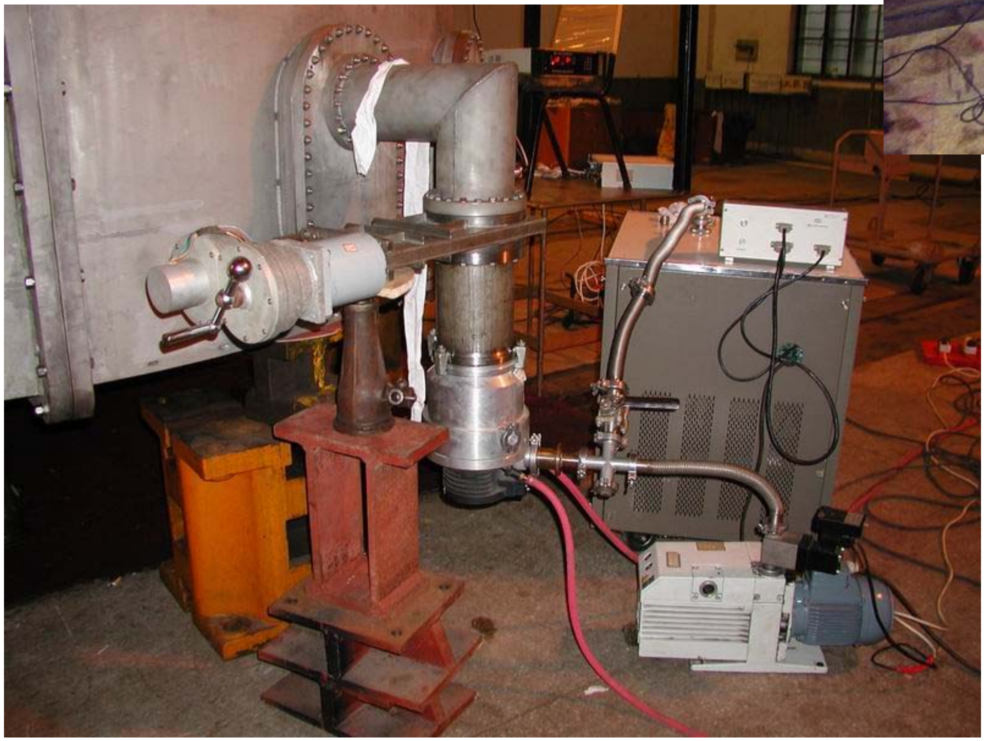
Assembling TF Coils on to the Vacuum Vessel

Setting the assembly
on its stand

Completing the test assembly

Trial Assembly
Complete
Shanghai Boiler Works
March 2002

Vacuum Leak Test



Assembly

The apparatus arrived at the University of Texas in October 2002. Over the next four months, it was assembled and commissioned.

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The first truck
with the TF coils
and base plate

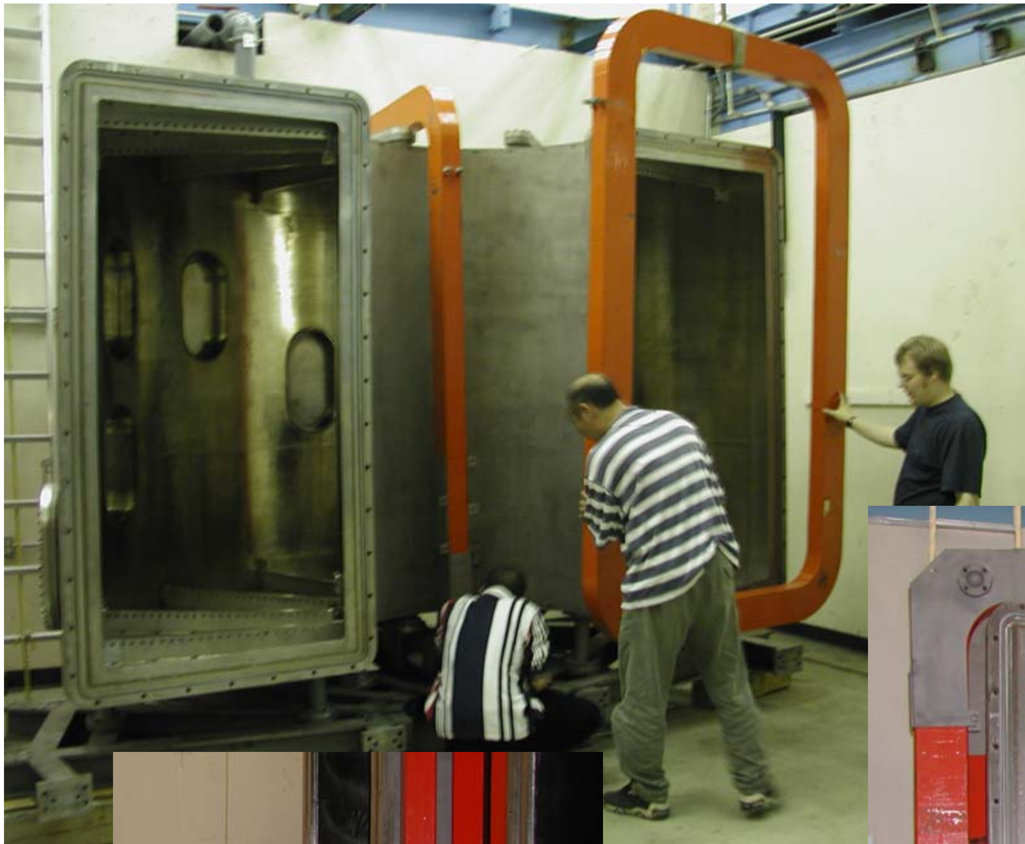
The second truck

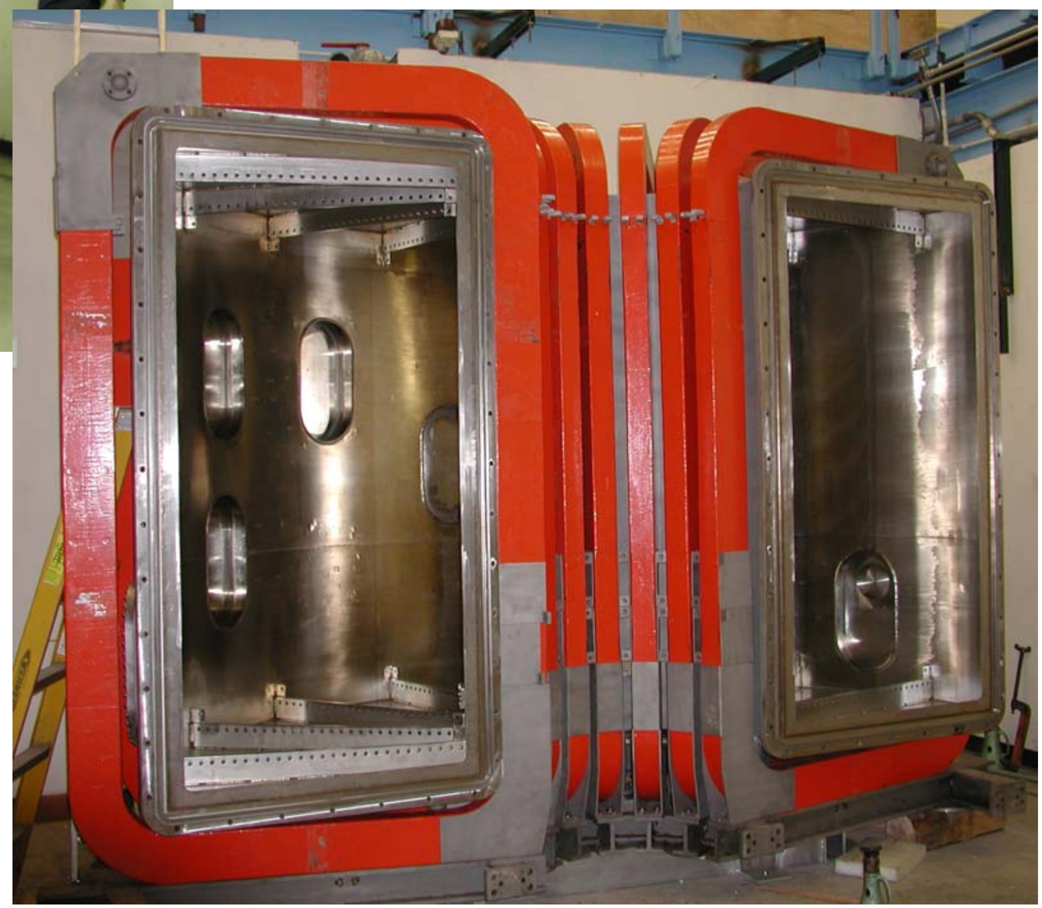
The lifting jig being lowered through the roof hatch into the underground laboratory

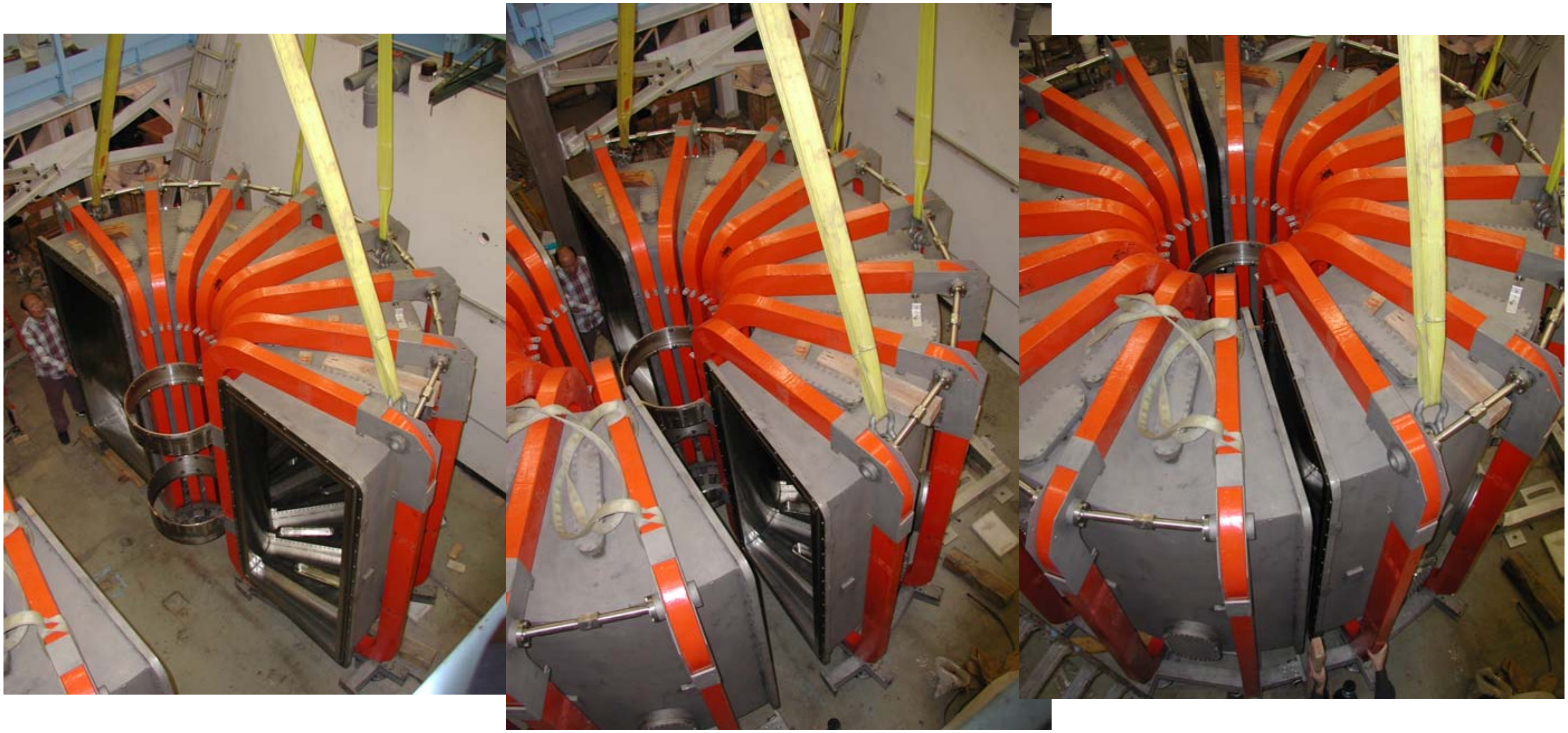
Unloading the vacuum vessel

The VF coils,
a tight fit

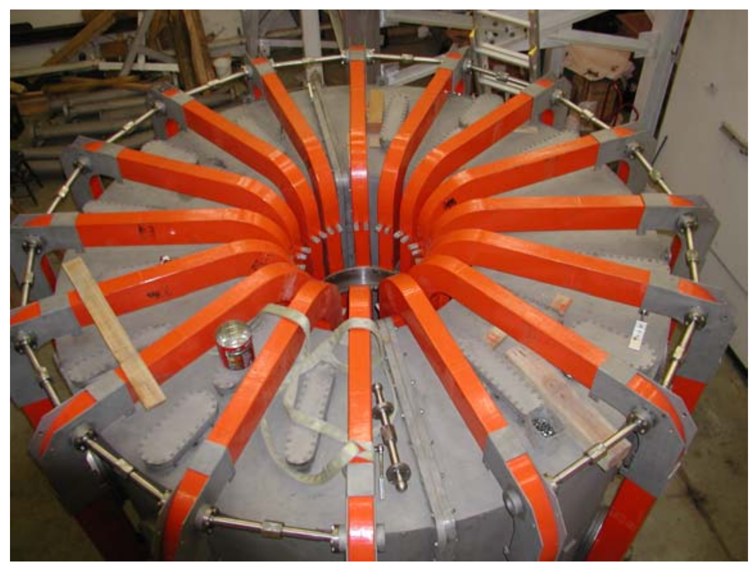
Threading the TF coils on to the vacuum vessel







Mating the halves



The final lift

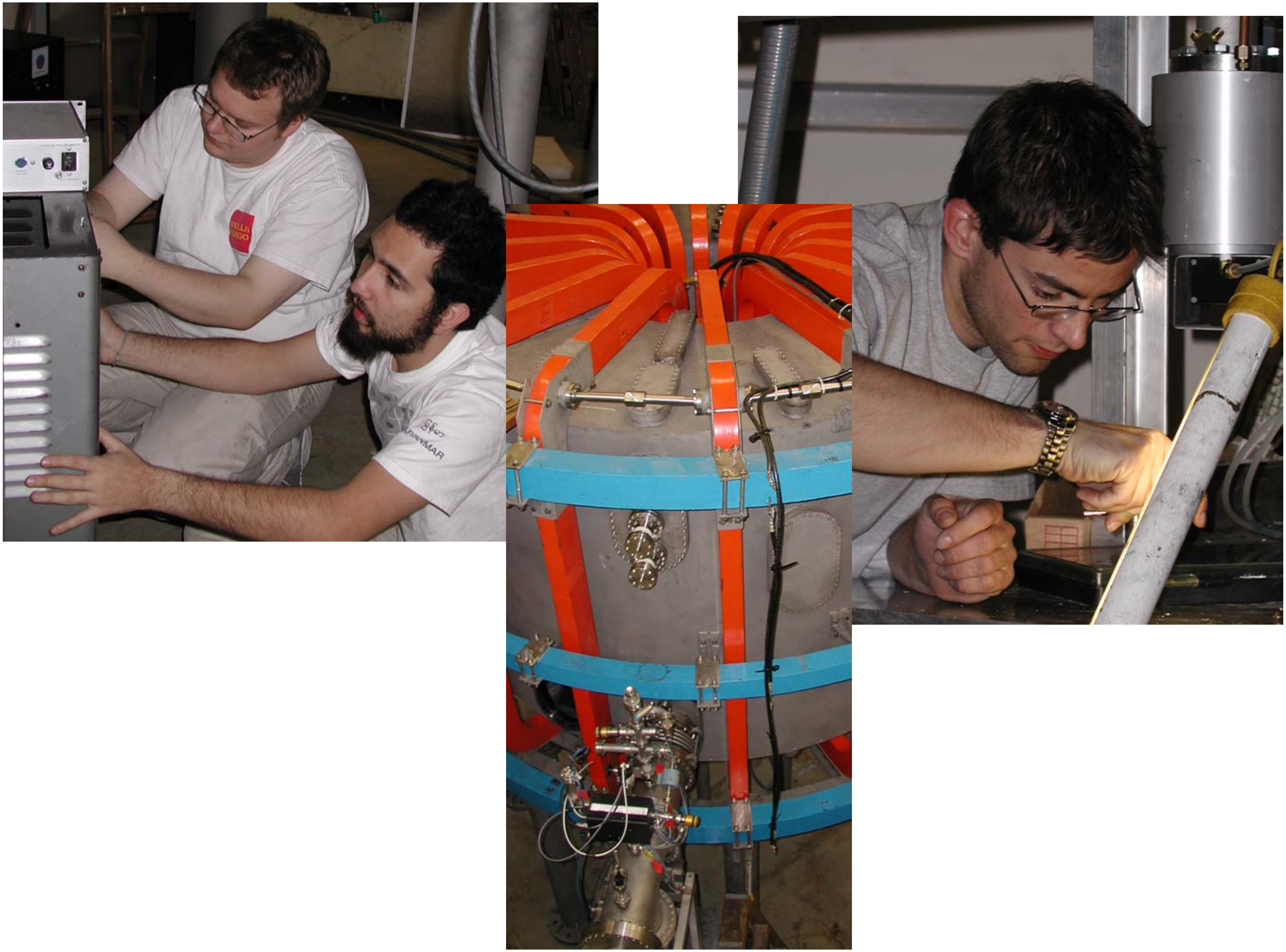
Completing the coil assembly

The Crew

Huang He

Ken Gentle

Keith Carter



Operation

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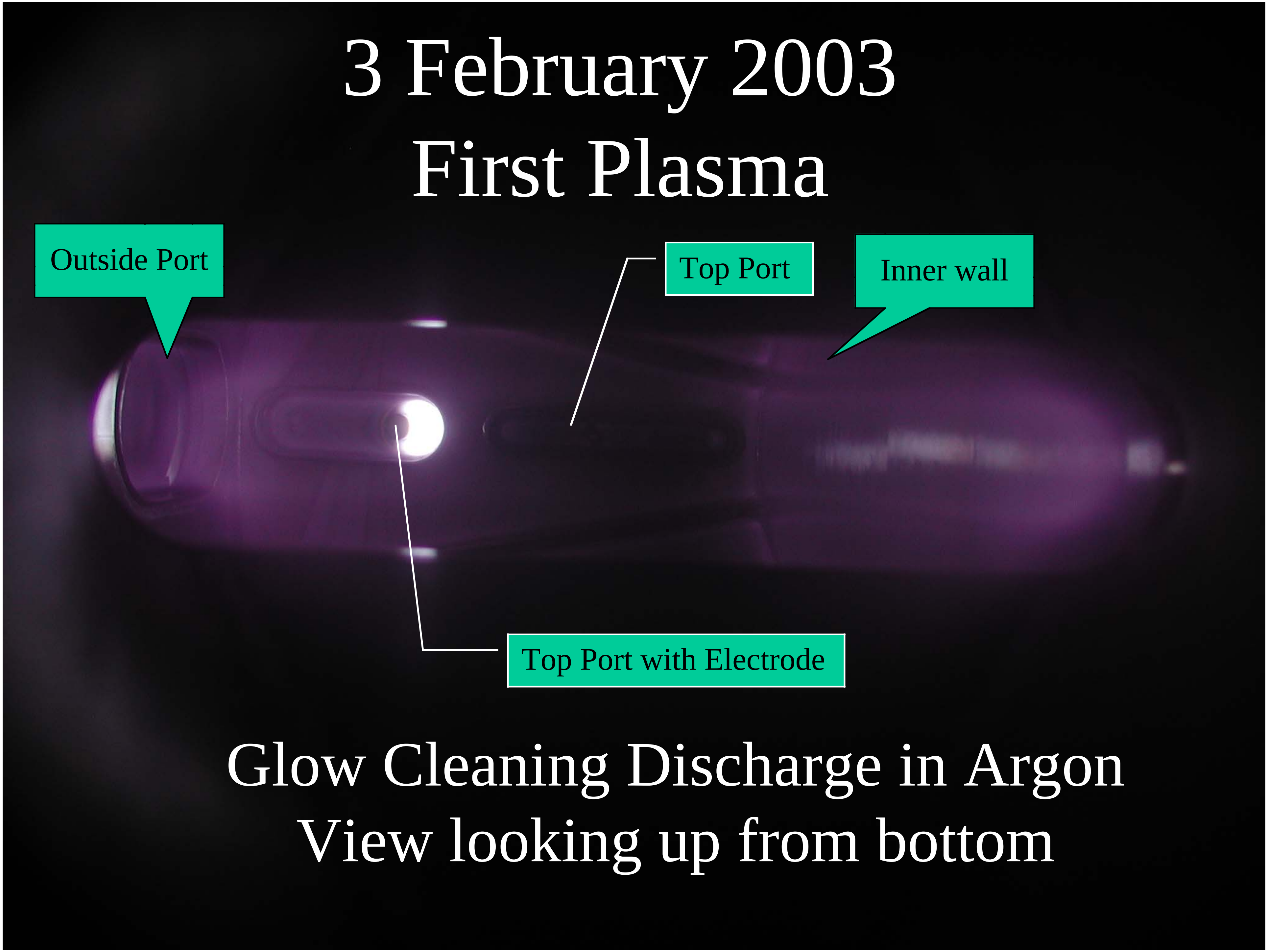
3 February 2003
First Plasma



Glow Cleaning Discharge in Argon
View looking up from bottom

Plans

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- The first objective will be to characterize the plasmas produced in the device: densities, temperatures, profiles
- The second objective will be to characterize the turbulence -- frequencies, wavelengths, dependence on plasma parameters -- for comparison with relevant codes, e.g. those of Bruce Scott at Max-Planck-Institut für Plasmaphysik, Garching
- The third objective will be to impose controlled radial electric fields to determine the effects of flow shear on the turbulence

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