Progress in application of High Temperature Superconductor in Tokamak Magnets

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FIRST TESTS of HTS for MAGNETS ON A TOKAMAK, GOLEM, CZECH TECHN. UNIV., August 2011

Abstract – It has long been known that high temperature superconductors **(HTS)** could have an important role to play in the future of tokamak fusion research. Here we report on first results of the use of HTS in a tokamak magnet (**GOLEM**, Czech Technical University at Prague) and on the progress in design and construction of the first fully-HTS tokamak (**ST25**, Culham Science Centre).

Introduction

• In 2011, **Tokamak Solutions** and **Oxford Instruments**, in collaboration with the Czech Technical University in Prague, carried out the first successful tests of an HTS coil on a tokamak. In the experiments, two of the copper poloidal field (PF) coils on the Golem tokamak in Prague were replaced with a pair of liquid nitrogen cooled coils each of 6 turns of HTS (RE)BCO tape material manufactured by SuperPower (US).

• Like traditional low temperature superconductors, HTS conduct current with zero electrical resistance so that coils can be run without any resistive heating. Although superconductivity in HTS is achieved at liquid nitrogen temperatures, remarkable further improvement in performance is achievable at lower temperatures. **HTS promises much better performance** in all the main characteristics of importance for application in tokamak magnets: **higher fields, higher critical current, better irradiation resilience**.

Bench tests and no-plasma tests of HTS

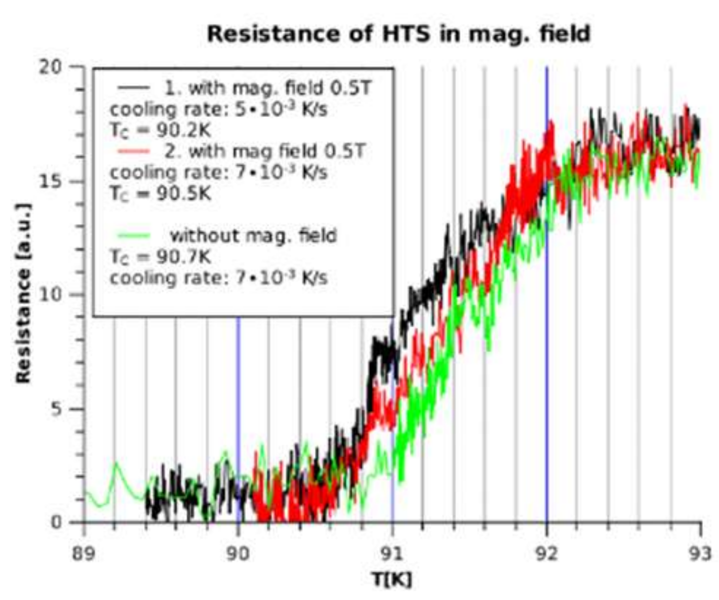

Fig.1. Superconductivity achieved at 91K with zero, or 0.5T external field, critical temperature does not depend on cooling speed or external field of 0.5T

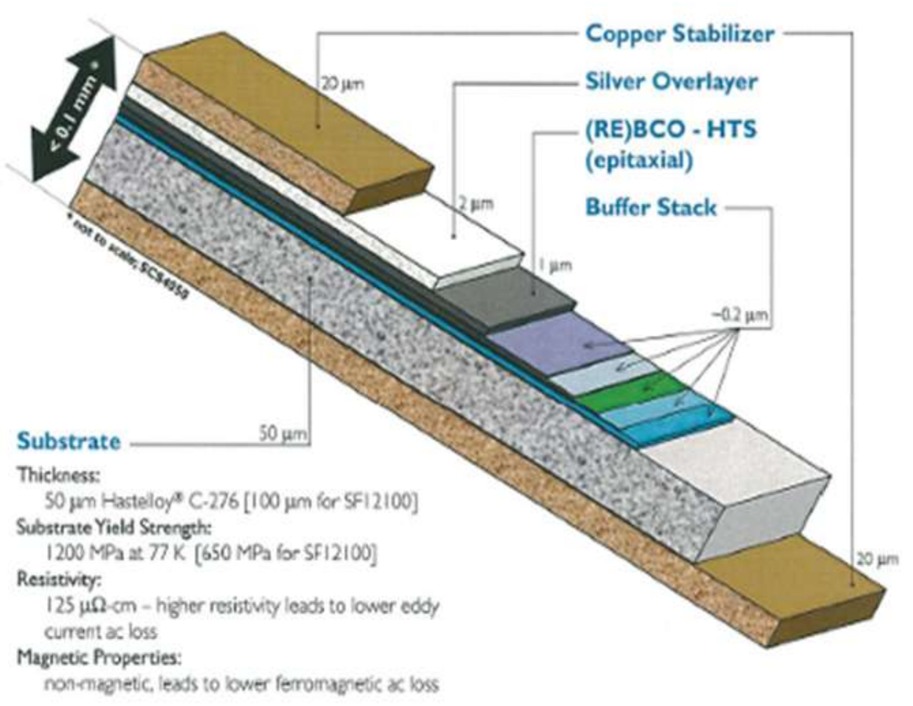

Fig.2. Structure of the (RE)BCO tape manufactured by SuperPower (US), used on GOLEM and ST25

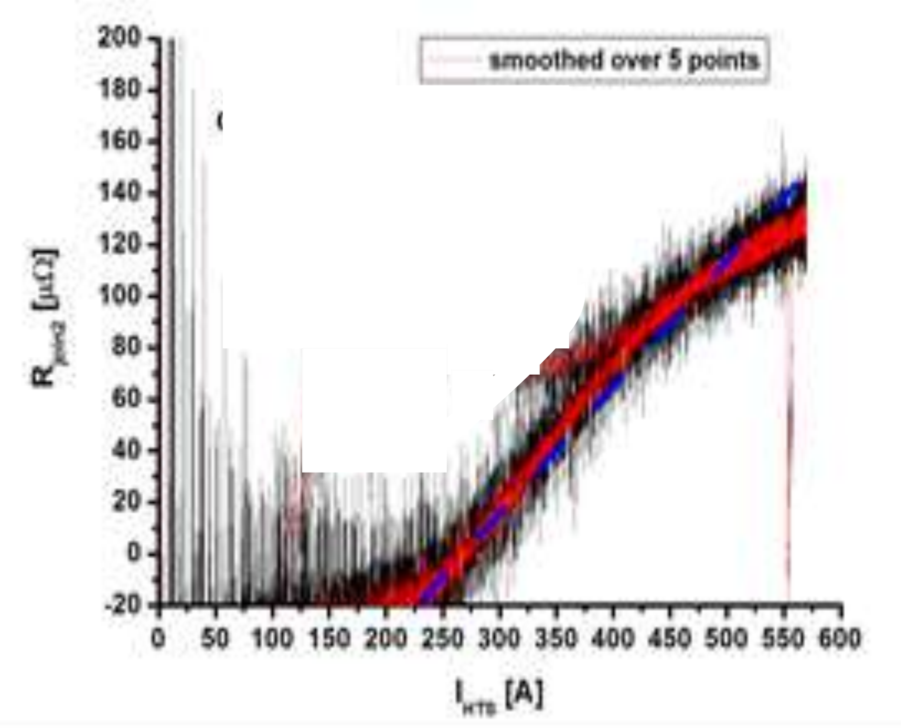

Fig.3. Resistivity over a soldered joint within one coil, i.e. with 40mk of Cu layer between HTS layers. Critical current of this tape ~330A

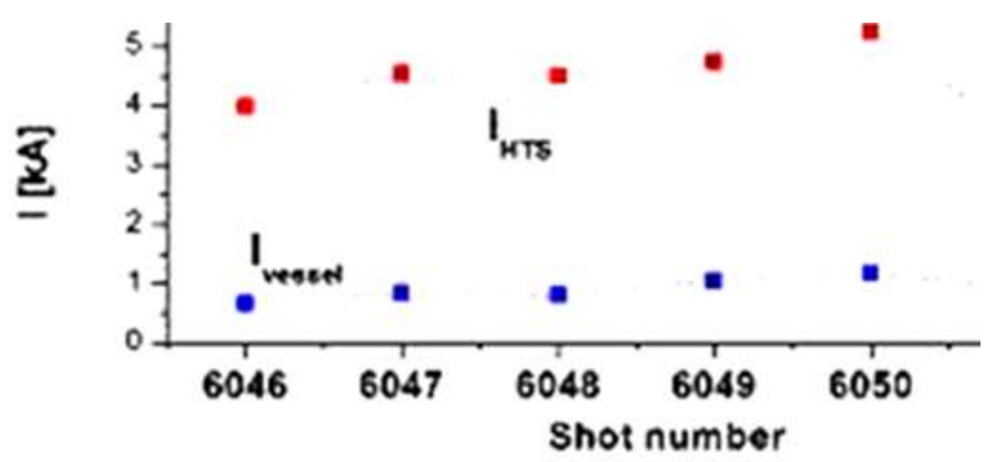

Fig.4. Maximum current in the coil 5.4kA (**840A** through the tape), which is 2.5 times higher than I_{crit} SuperPower specification;

• ***No degradation at these extreme loads***

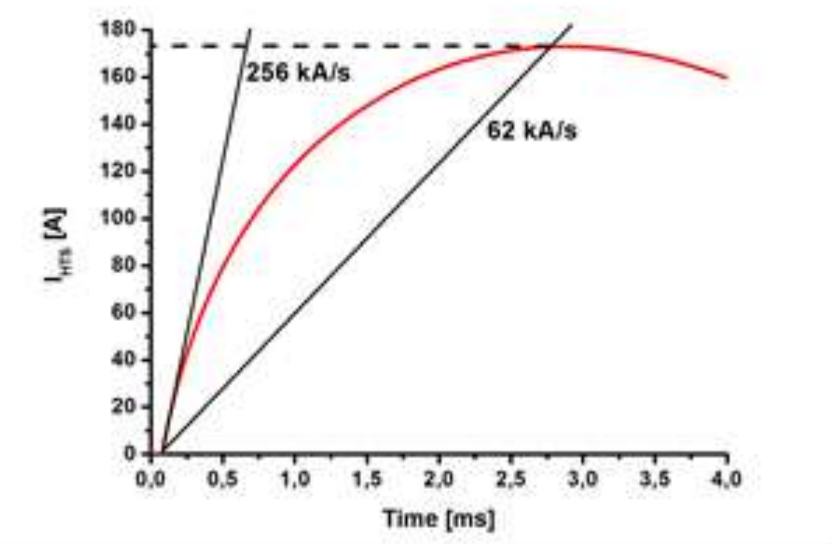

Fig.5. Current ramp-up speed ~ 100kA/s

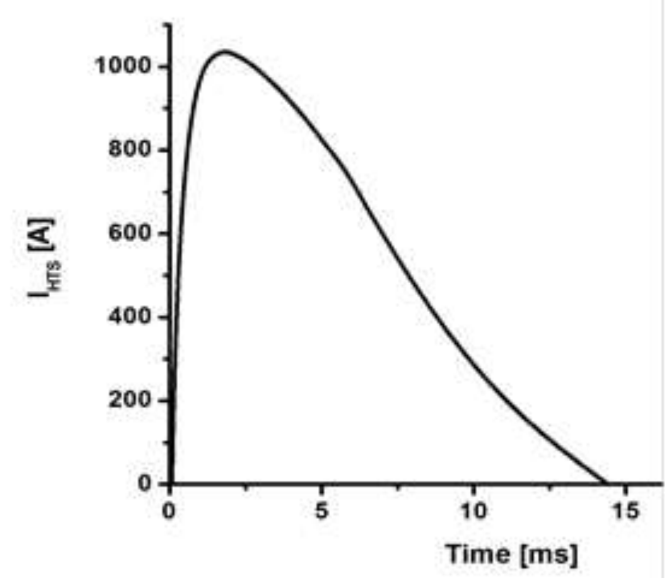

Fig.6. Evolution of the HTS coil current in record pulse 6975.

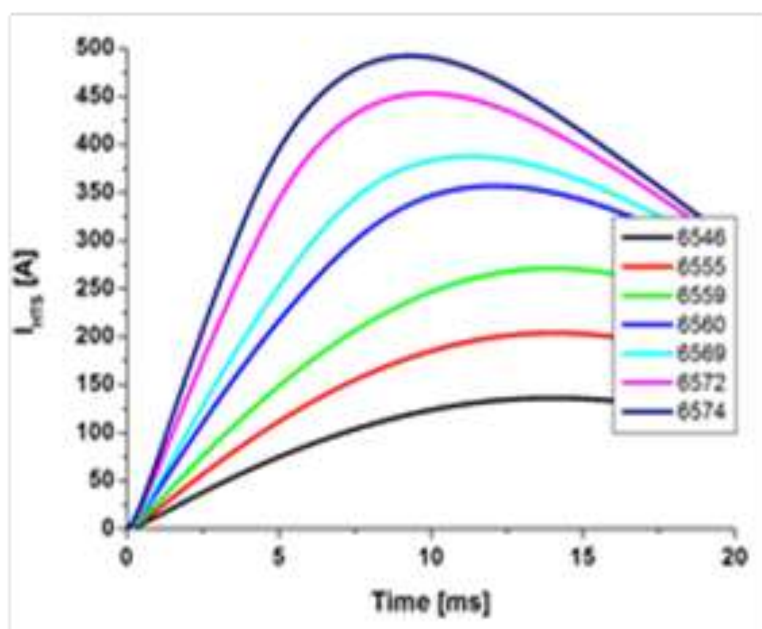

Fig.7. Evolution of the inductively induced current in the HTS coil in different pulses

Fig.8: Tokamak GOLEM with two HTS PF coils.

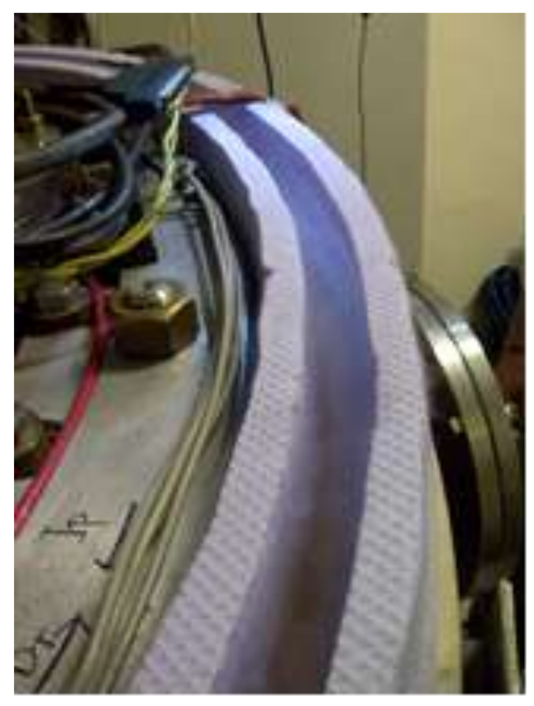

Fig.9. The final (open) version of the extruded polystyrene cryostat with 4 turns of (RE)BCO tape in each coil, cooled by liquid Nitrogen.

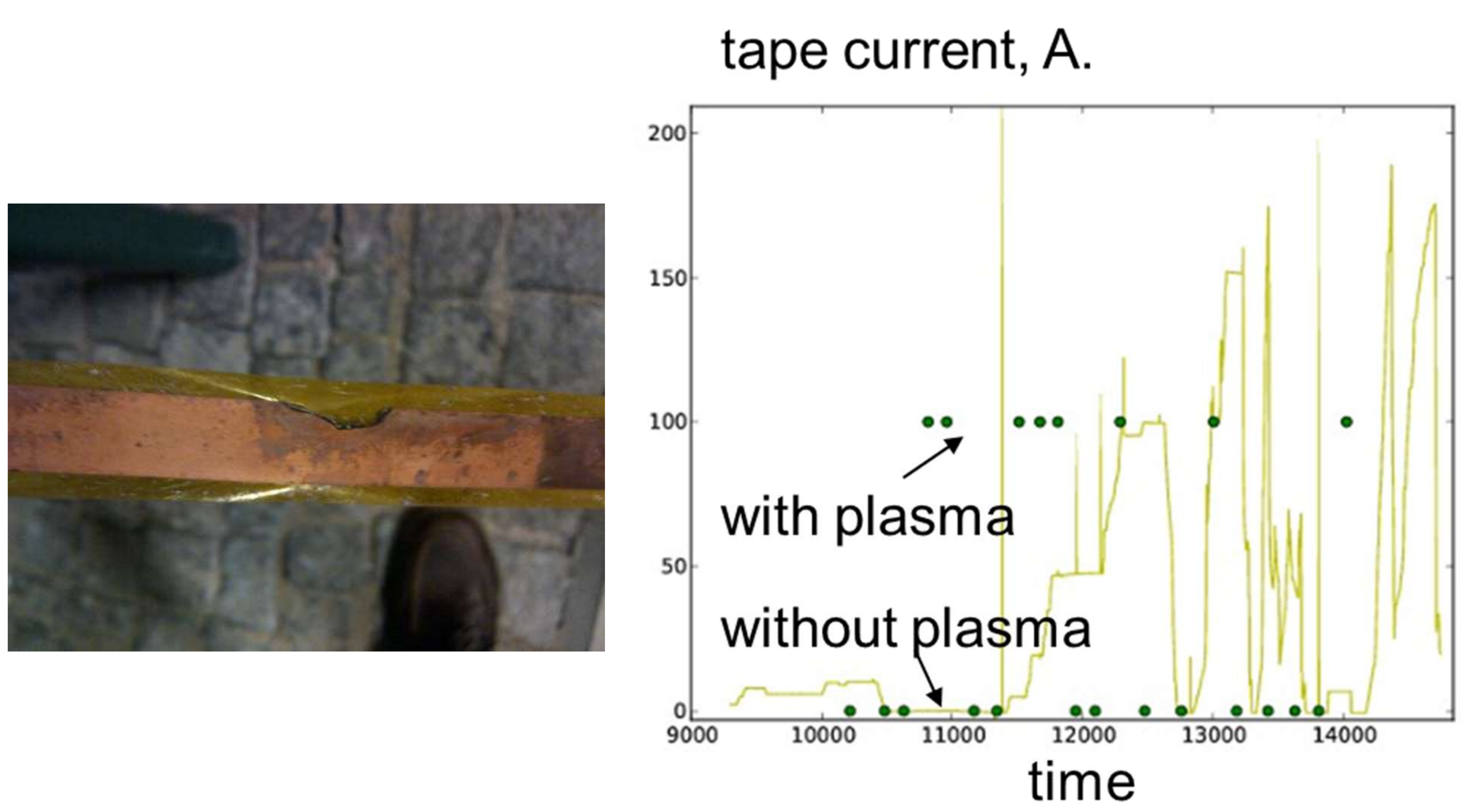

Fig.10. Left: HTS tape damaged in a forced quench; Right: Many pulses have been performed with and without plasma, no quenches below I_{HTS}~150A

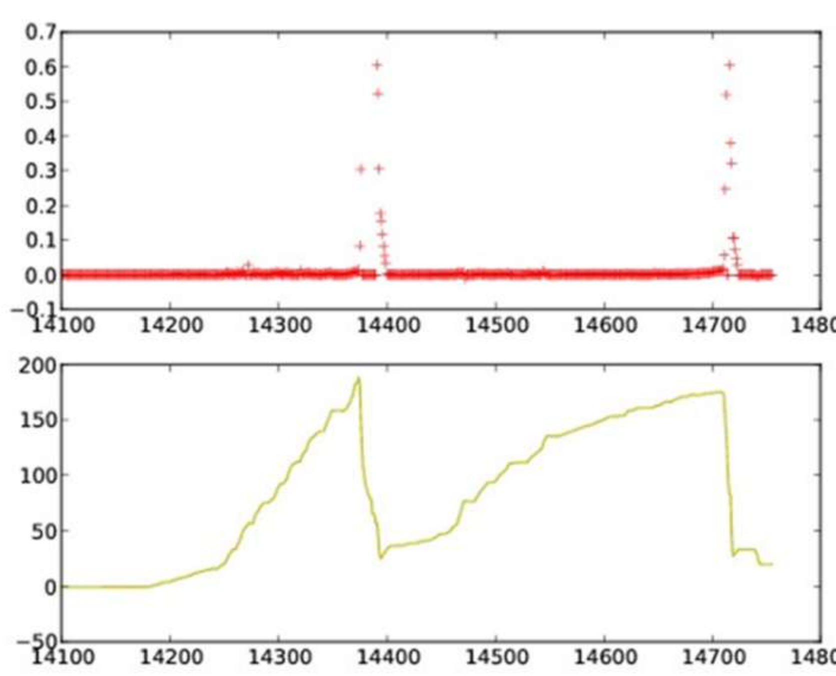

Fig.11. No HTS degradation observed after a controlled quench: top – voltage, bottom – current in HTS tape.

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FIRST TOKAMAK OPERATIONS with HTS PF COILS, Autumn 2011 & MOST RECENT RESULTS from 5th IAEA Joint Experiment, Prague, Czech Republic, September 2012.

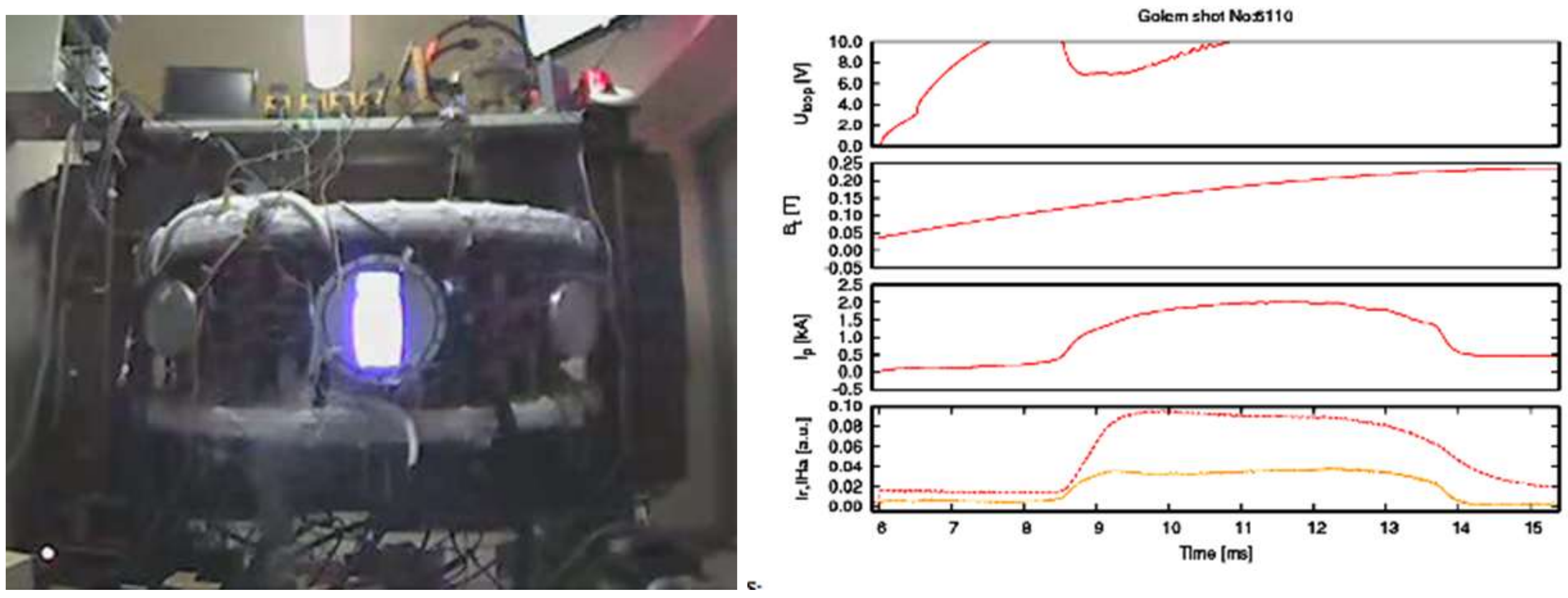


Fig.12: Typical plasma pulse in GOLEM with two HTS PF coils. By changing HTS coil current ant timing, it was possible to increase pulse duration by 2ms and to increase plasma current by 20-40%
At the same time, the breakdown and start-up loop voltage has been decreased from 10-20V to 4-10V

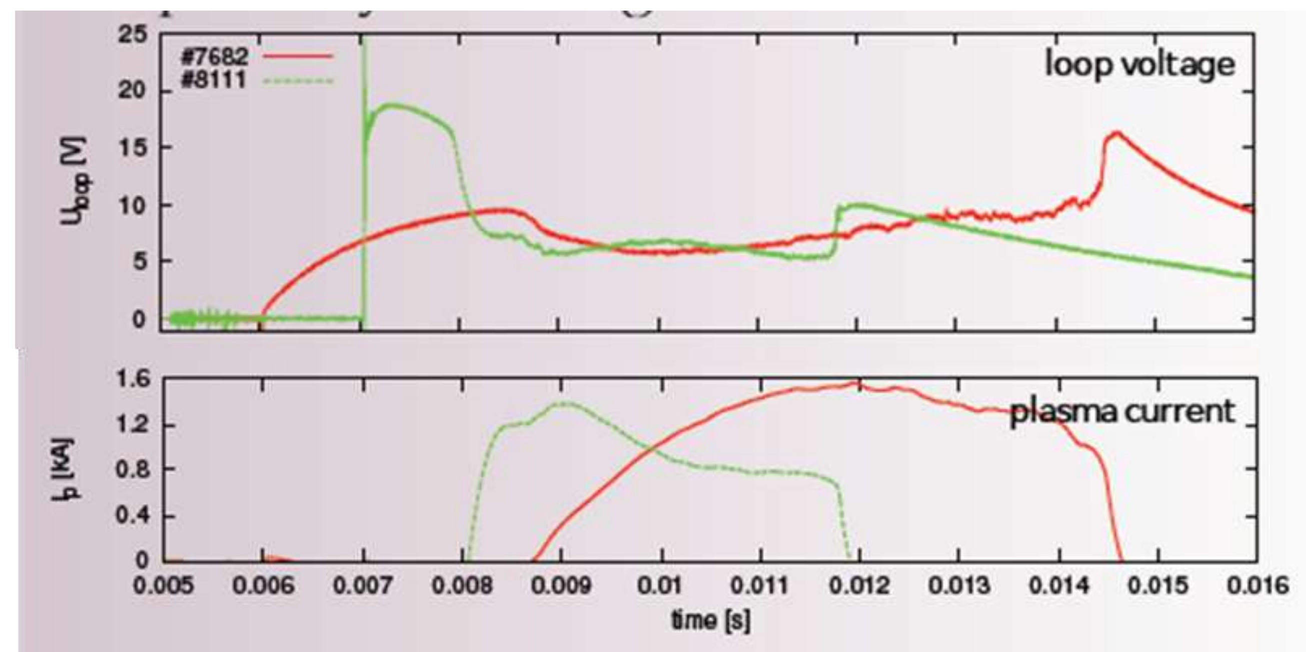


Fig.13. Green – no HTS coil current, poor equilibrium. Red – with HTS coils, b/d loop voltage reduced, less v-sec used, longer pulse.

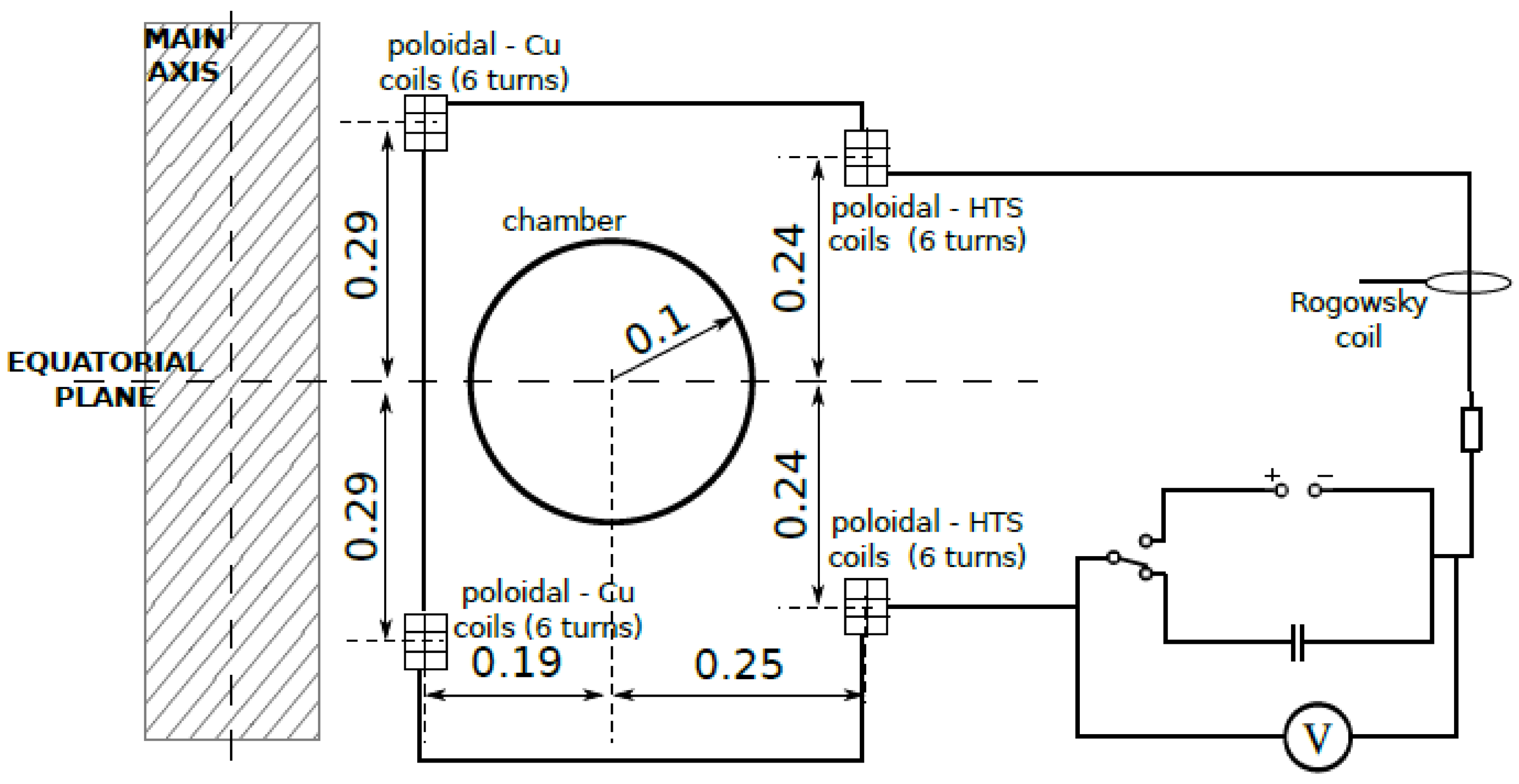


Fig.14. Connection of HTS coils in first experiments.

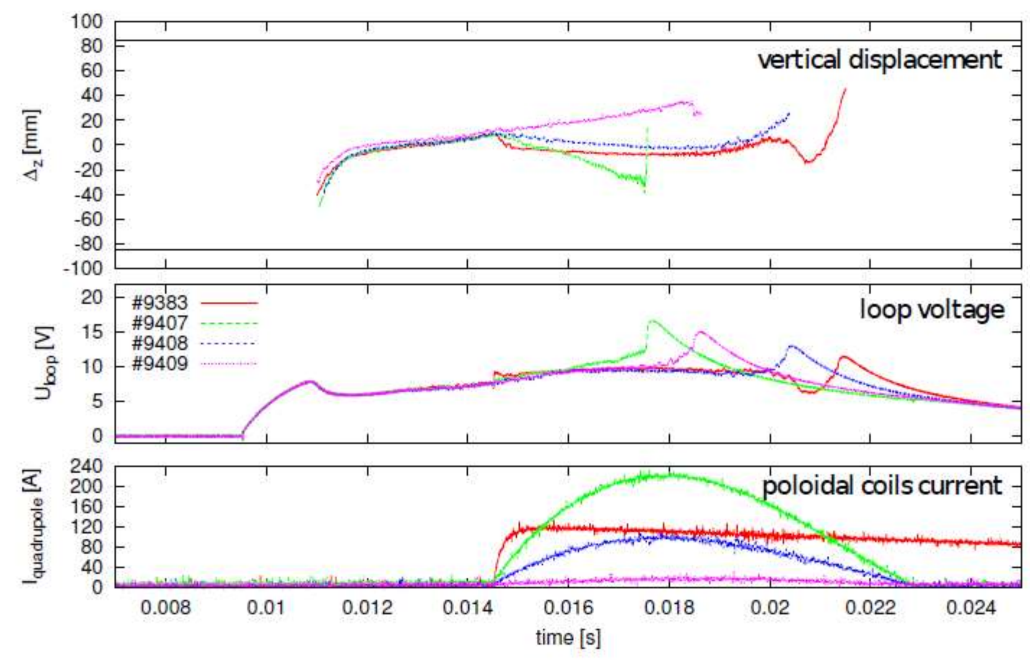


Fig.15: Top - Plasma vertical displacement in different pulses, using the HTS coils in discharges #9407 and #9408, #9383 in a non-superconductive state, #9409 is a reference discharge with no current in HTS coils. Middle – loop voltage. Bottom – current in HTS coils.

ST25 – THE FIRST TOKAMAK WITH ALL-HTS MAGNETS, CULHAM SCIENCE CENTRE, UK

- **Successful tests of HTS coils on GOLEM** provided enough confidence to design and start construction of the first **full-HTS tokamak, ST25**.
- ST25 main parameters:
  R/a = 25/12.5cm
  B_t = 0.1 - 1 T
  I_{pl}= 5-20 kA
  pulse duration: Cu coils 1 – 5 s
  HTS coils: s/state
  current drive: EBW 3 – 20kW
  wall conditioning: Li
  divertor/limiter: liquid Li

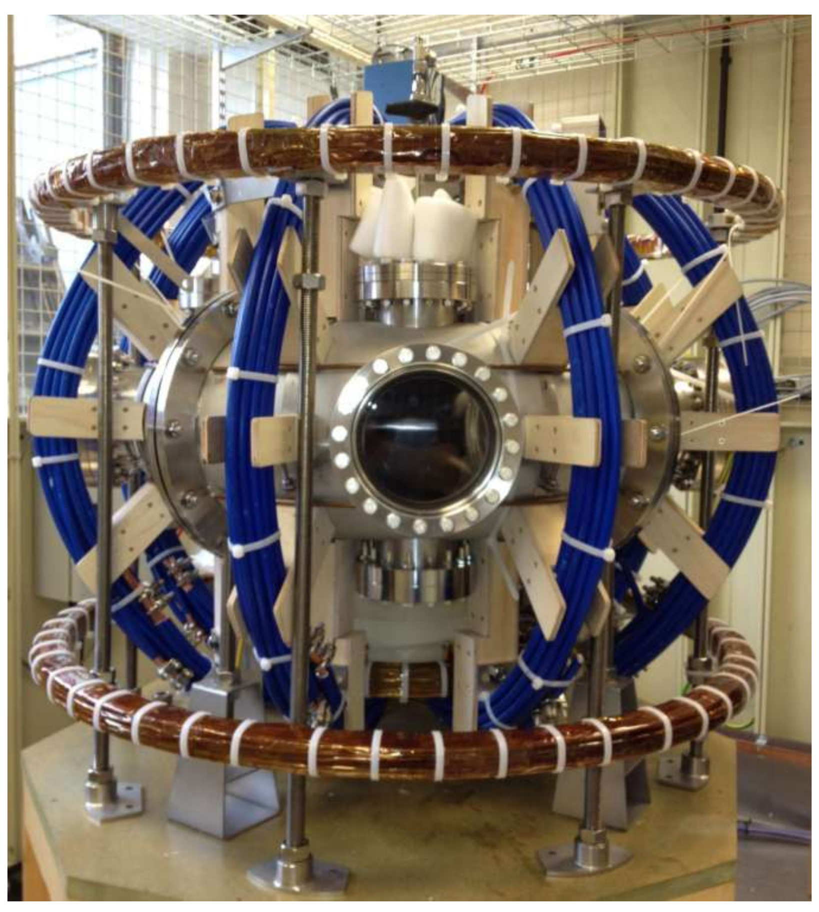


Fig.16: ST25: present status (Cu magnets). First tokamak plasma achieved in October 2012

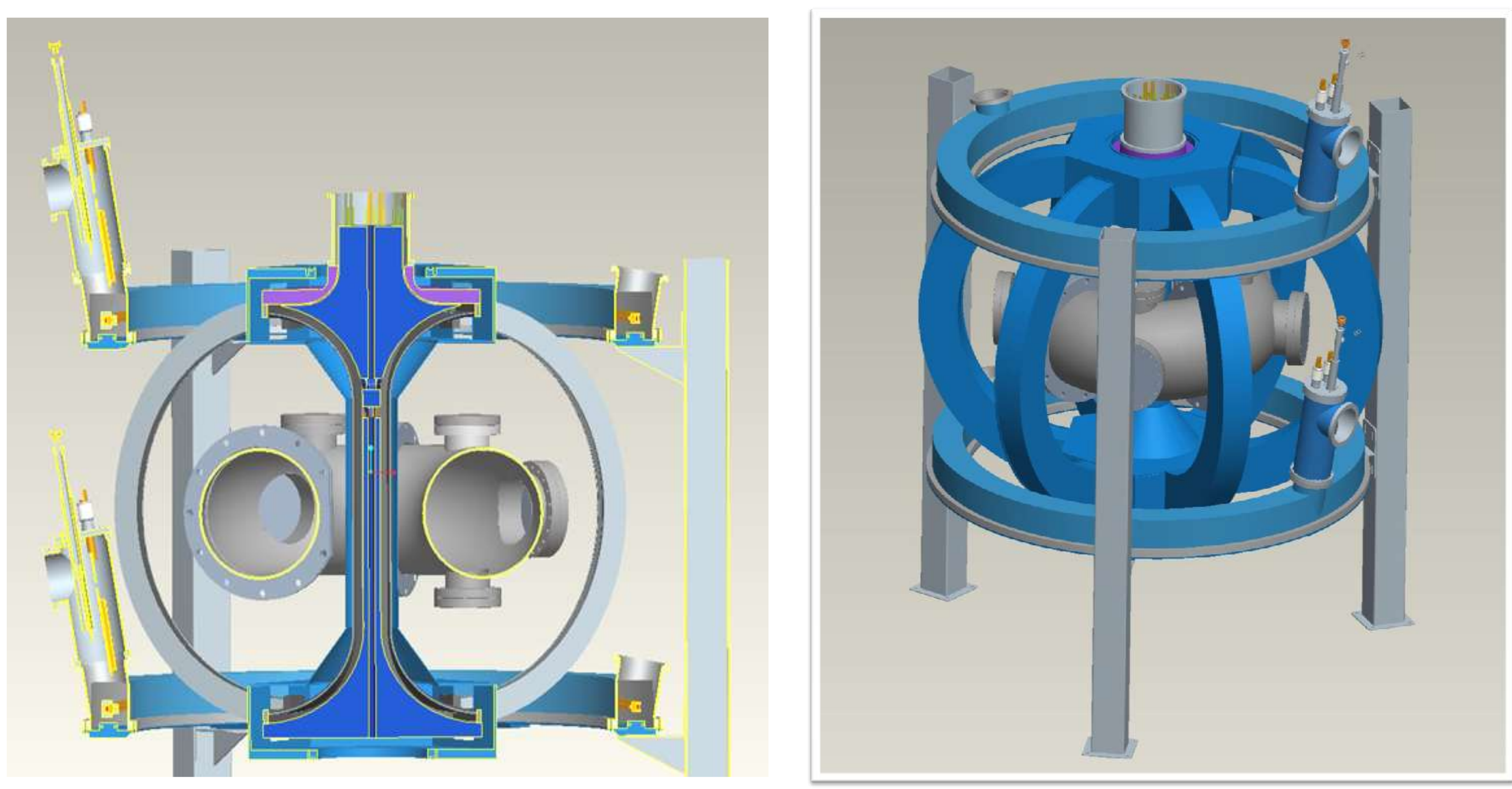
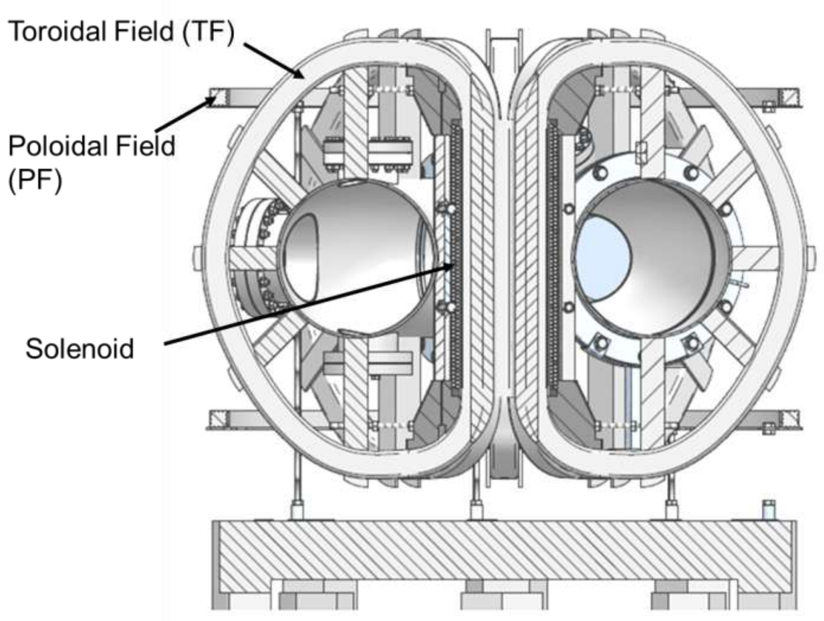


Fig.18: Oxford Instrument's design of TF and PF HTS magnets, magnets under construction;



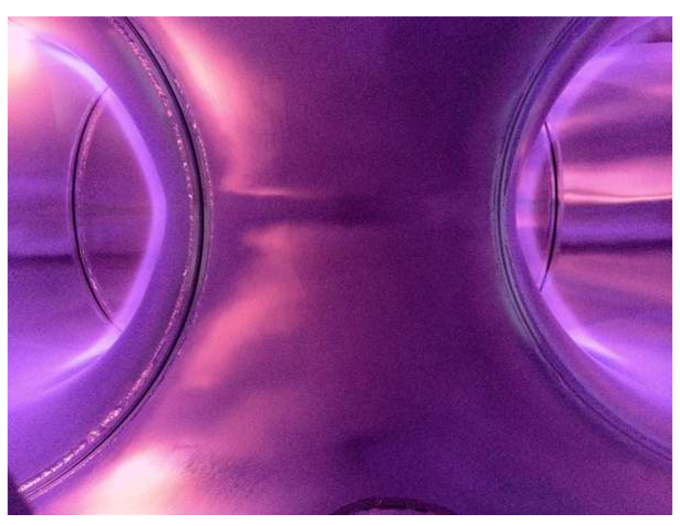
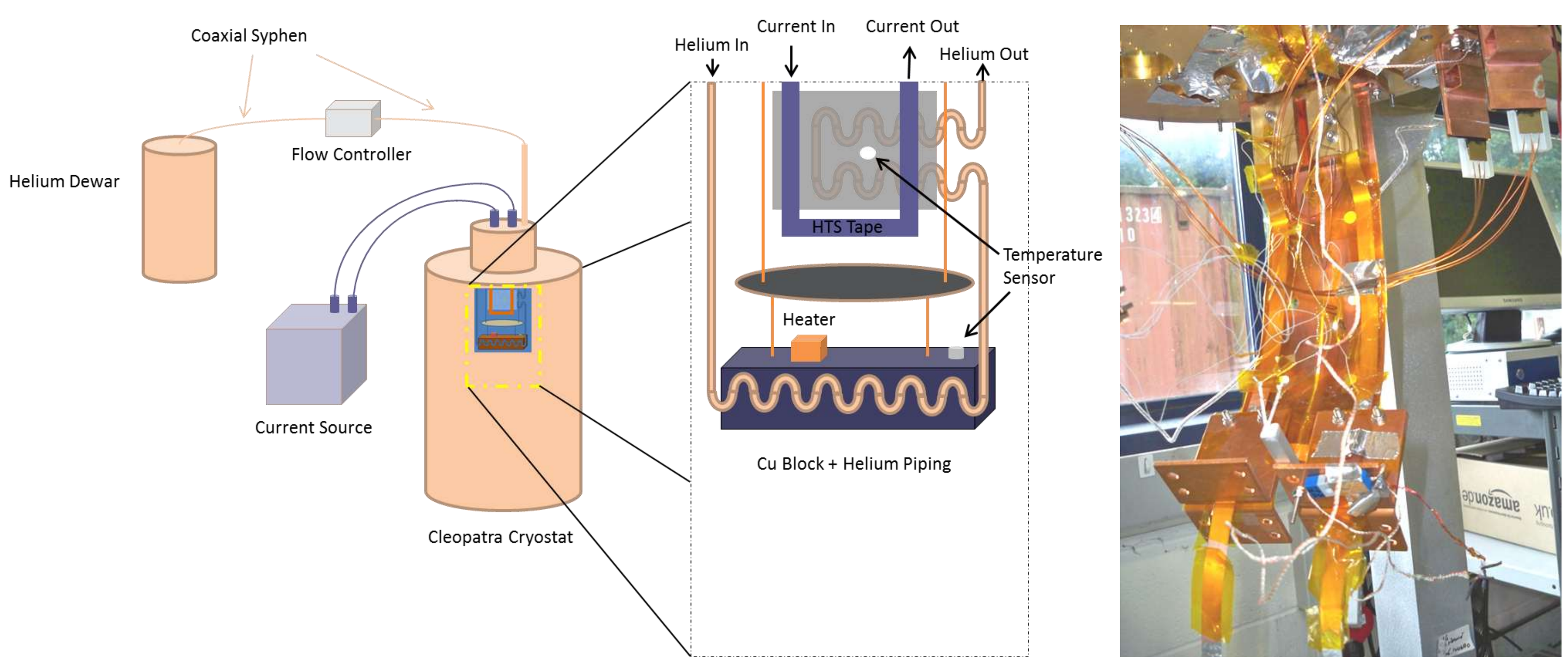


Fig.17*:* glow-cleaning discharge in argon



Fid.19. CLEOPATRA LHe Experimental Stand for HTS feeds studies @ Oxford Instruments

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